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GEOLOGY AND MINERAL RESOURCES OF THE TEMPLE AND FLEETWOOD QUADRANGLES, BERKS COUNTY, PENNSYLVANIA

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Pennsylvania Geological Survey

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GEOLOGY AND MINERAL RESOURCES OF THE TEMPLE AND FLEETWOOD QUADRANGLES, BERKS COUNTY, PENNSYLVANIA

by
David B. MacLachlan

ABSTRACT

The mapped area comprises approximately 117 square miles (303 km^2) in three geologically and topographically distinct terrains in the Great Valley and New England provinces. This report treats areal geology, stratigraphy, and structure of Cambrian and Ordovician sedimentary rocks and summarizes previous publications on Precambrian crystalline rocks, presenting a new interpretation of their structural position. A complex structural evolution involved emplacement of the Hamburg sequence of allochthonous, predominantly argillaceous rocks related to the Taconic sequence of New York and Vermont. Development of parautochthonous nappe structures in partially contemporaneous, predominantly carbonate rocks of the Lebanon Valley sequence occurring in the Lebanon Valley nappe, and of the Lehigh Valley sequence occurring in the Irish Mountain nappe, was concurrent or soon followed.

Precambrian para- and orthogneisses and migmatites and topographically associated basal quartzite of the Lehigh Valley sequence underlie the Reading Prong hills of the New England province. Parts of these rocks occur as remnants of a crystalline core in the Irish Mountain nappe. A major part, however, was detached and finally emplaced on the Alleghanian Grings Hill thrust in association with rocks of the Lebanon Valley sequence similarly emplaced on the Sinking Spring thrust. Aeromagnetic data indicate that exposed gneiss bodies are only moderately thick, that there are buried detached masses, and that all gneiss bodies lie in a complex sequence of parautochthonous and allochthonous Lower Paleozoic sediments that have no connection to basement.

Folds and some second cleavage were impressed on rocks previously deformed by the Taconic movements, probably contemporaneously with the low-angle Alleghanian thrusting. Late Alleghanian and Mesozoic high-angle faulting further complicates the present geologic pattern.

The Irish Mountain nappe and closely related structures containing sedimentary rocks of the Lehigh Valley sequence dominate in the geologic map and sections. The rocks are assigned to previously described formations and include type sections for the subdivision of the eastern Pennsyl-

vania Beekmantown Group. Three new members are defined and mapped in the Upper Cambrian Allentown Formation.

Evidence bearing on the age of the allochthonous Hamburg sequence points to early Middle and older Ordovician age, and a few new fossil occurrences are described. These rocks have been mapped in seven recently defined lithotectonic units.

Rocks of the Lebanon Valley sequence are confined to the upper plate of the Alleghanian Sinking Spring thrust, which is poorly exposed locally near the south edge of the area. This thrust sheet is apparently derived from the upper limb of the Lebanon Valley nappe and is mapped as containing formations previously described in the Lebanon Valley.

Major factors of the geologic environment affecting human activities have been summarized on Plate 2 to avoid the confusing aspects of geologic detail that are only incidentally relevant to most land uses. A limited number of environmentally distinct areas that have fairly consistent internal properties for most engineering purposes are defined. Sinkholes and related solution features in areas of carbonate-rock exposure are the principal geologic hazards in the mapped area.

Mineral products presently produced in the mapped area include crushed limestone and dolomite, and quartzite, portland cement, and brick. These industries are quite significant in the local economy. Alluvial coal and some gravel have been produced and some future production is possible. Small magnetite and "brown ore" deposits formerly supported a local iron and pigment industry. Deposits comparable to those mined are still present, but they are not economically producible under forseeable conditions. Some prospecting potential for zinc, uranium, and possibly other minor minerals is indicated.

INTRODUCTION

The mapped area comprises the Temple and Fleetwood 7-1/2-minute topographic quadrangles, which form the northern half of the Reading 15-minute quadrangle. Bounding 7-1/2-minute quadrangles, which may be referred to in later text descriptions, are Auburn to the northwest, Hamburg and Kutztown to the north, Topton to the northeast, Manatawny to the east, Boyertown to the southeast, Birdsboro and Reading to the south, Sinking Spring to the southwest, and Bernville to the west.

Hills of Precambrian gneiss and Lower Cambrian quartzite occupying most of the southeastern third of the area form part of the Reading Prong of the New England physiographic province (Figure 1). The flanking valleys are developed on Cambrian to locally Middle Ordovician carbonate rocks, which were complexly folded and thrust-faulted during the development of Ordovician (Taconic) nappes and underwent later thrusting near the end of

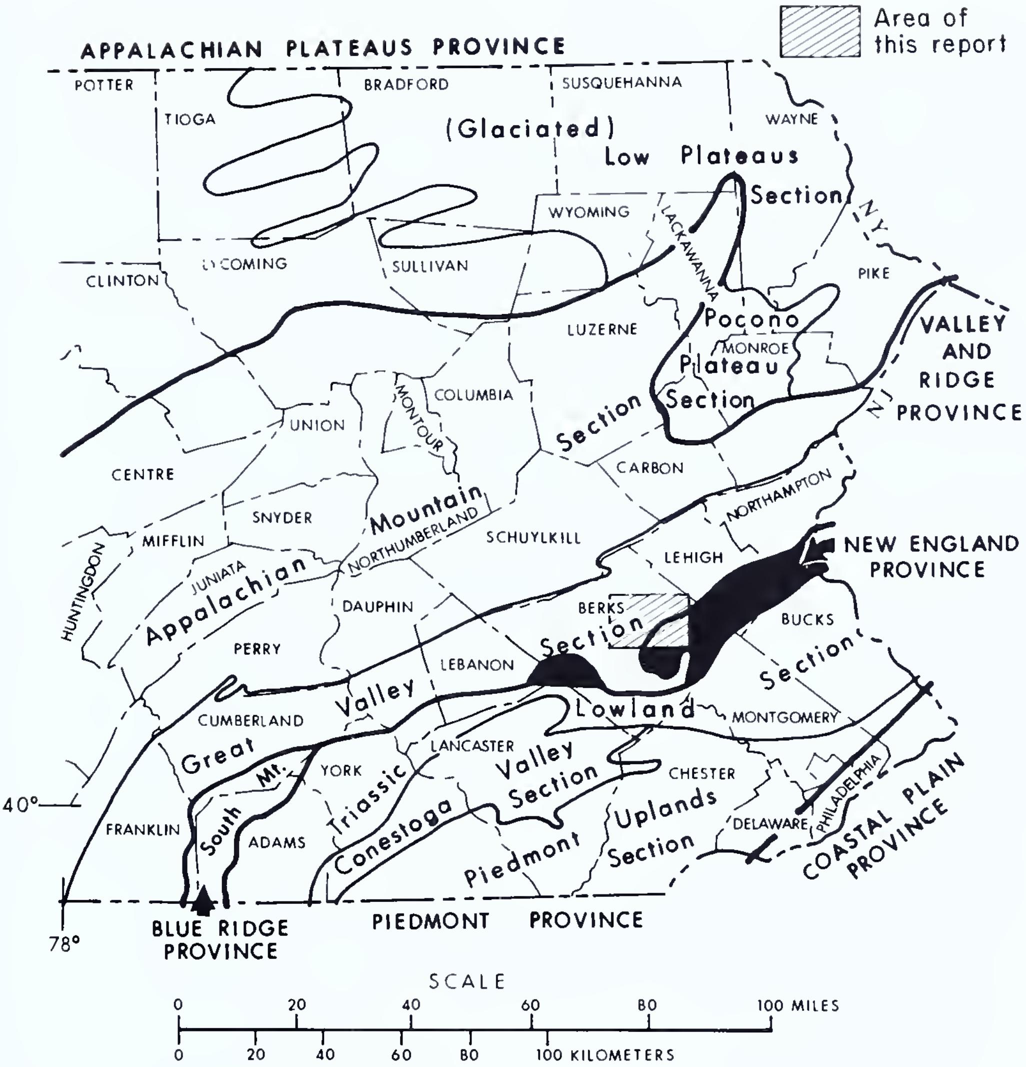

Figure 1. Physiographic provinces of Pennsylvania and the location of the area of this report. The Reading Prong section of the New England province is shown in black.

the Paleozoic (Alleghanian). These rocks are interpreted to underlie the quartzite and gneiss hills also. More subdued hills of shale, primarily in the northwestern quarter of the area, are mostly underlain by allochthonous rocks of the Hamburg sequence, emplaced during the Taconic orogeny. The shale and carbonate rocks collectively form part of the Great Valley physiographic province. Later high-angle faulting juxtaposed rocks of different thrust levels and added to a complex structural pattern.

The Hamburg sequence was evidently emplaced just prior to the development of the Irish Mountain nappe, which comprises most of the shelf-facies rocks in the area. These rocks are similar to those in the Lehigh Valley and are referred to as the Lehigh Valley sequence. The rocks in small areas near the south edge of the mapped area evidently are more closely related to rocks of the Lebanon Valley (Lebanon Valley sequence) and are believed to be remnants of the Lebanon Valley nappe. Present relationships, however, are evidently attributable to the later stage thrusting.

Rocks younger than Middle Ordovician are represented only by one Mesozoic diabase dike and various unconsolidated Quaternary deposits.

PREVIOUS WORK

Except for the crystalline rock and Hardyston Quartzite of the Reading Prong, which were mapped by Buckwalter (1962), the only large-scale geologic map of this area previously published is that of D'Invilliers (1883), which is a useful source for certain details, especially pertaining to mining, but it is essentially obsolete. G. W. Stose and A. I. Jonas did reconnaissance mapping in the area, probably in the period 1925-1935, which is reflected in the 1932 Geologic Map of Pennsylvania (Stose and Ljungstedt, 1931), and influenced compilation of the 1960 Geologic Map of Pennsylvania. Their recognition of the Reading overthrust (Stose and Jonas, 1935) and the Taconic (Hamburg) sequence (Stose, 1946, 1950) represents the beginning of modern structural interpretation of this area; the Reading overthrust proposal caused considerable controversy (Miller and Fraser, 1935; Fraser, 1938; Miller, 1944).

Gray (1950) first recognized the existence of nappe-like structures in the carbonate rocks and demonstrated that the Beekmantown Group was divisible (Gray, 1951). Formal division of the Beekmantown was made by Hobson (1957, 1963), largely on the basis of exposures in the Temple quadrangle. His units are utilized in this report, and have been successfully extended through most of eastern Pennsylvania and New Jersey.

Aeromagnetic mapping (Bromery and others, 1960; Bromery and Griscomb, 1967) provides the basis for reinterpreting the faulting shown by Buckwalter (1962) in the Reading Prong, but little can be done to improve his painstaking lithologic mapping which, with a few peripheral amendments, is used in this report.

ACKNOWLEDGEMENTS

Carlyle Gray provided the initial direction for this report, introduced the author to many complexities of the area, and provided field notebooks and unpublished material on quarries in the area. Dan Kovaks and the Allentown Portland Cement Company provided generously of their knowledge of the area as well as data from their Evansville plant. Tracy Buckwalter provided not only his published data used in this report, but also manuscript maps by Stose and Jonas, and valuable discussions.

Charles Wood of the U. S. Geological Survey provided the water well data that are critical to certain interpretations and did a major part of the mapping in the Hamburg sequence, which was part of a concurrent cooperative study of groundwater in northern Berks County (Wood and MacLachlan, 1978). The author is indebted to Paul Myers of Lehigh University, whose detailed study to the west provided the framework for subdivision of the Hamburg sequence in Berks County and who provided consultation in the field. Ina Alterman provided substantial alterations to her thesis reconnaissance map (Alterman, 1971), and accompanied the author in the field. William Berry of the U. S. Geological Survey identified graptolites collected by the author.

Samuel I. Root served as a sounding board for numerous hypotheses, and materially improved this atlas through his comments.

STRATIGRAPHY

Precambrian granitic gneisses (800 to 1,000 million years old) intrude and replace older gneisses that are partly of apparent metasedimentary origin. The gneisses are mantled by Paleozoic rocks ranging from Early Cambrian to Middle Ordovician age. The Lower Cambrian is predominantly quartzite containing a basal conglomeratic phase and is succeeded by a thick, predominantly dolomite and limestone section extending into lowest Middle Ordovician. The uppermost part of the carbonate succession is shaly and grades into overlying Middle Ordovician shale. Allochthonous slices of distinctive argillite, siltstone, graywacke, and some interbedded limestone, which are partly contemporary with the younger carbonate rocks, have been emplaced in the shale area and make up most of the clastic terrane of the northwestern part of the mapped area. These rocks are believed to have been emplaced during the Middle Ordovician as a part of the Taconic orogeny.

The rocks lie in a system of major thrust slices or nappes, which juxtapose rocks of similar age but of somewhat different facies. Such stratigraphically distinct assemblages have been designated "sequences." The Hamburg sequence comprises the allochthonous rocks of the shale terrane (MacLachlan and others, 1975). Parautochthonous Lower Paleozoic sediments mantling the Precambrian rocks of the Reading Prong are generally similar from this area eastward and have been assigned to the Lehigh Valley sequence (MacLachlan, 1967). These rocks form about 98 percent of the mapped area of Paleozoic sediments. Rocks of the Lebanon Valley sequence occur mostly under surficial cover in a small area west of Bernharts Reservoir, and probably appear also in the western Oley Valley; these rocks belong to a structurally higher nappe.

Diabase dikes of Early Paleozoic, and Late Triassic or Early Jurassic age locally intrude older rocks.

Deposits of Quaternary colluvium are extensive around the quartzite-gneiss hills but are commonly thin. Quaternary alluvial deposits occur along the Schuylkill River and in the Oley Valley. Somewhat older terrace deposits containing clasts of Middle Paleozoic rocks derived from north of the mapped area are sporadically distributed along the course of the Schuylkill River.

Descriptions of the various units are given on the legend of the geologic map (Plate 1). More detailed descriptions appear in the following section only for units that are not adequately described in other publications.

STRATIGRAPHIC SEQUENCES

Three stratigraphically distinct bedrock terranes of generally similar age occur in the mapped area (Figure 2). The rocks in each have been designated as forming a sequence, named after the geographic area where it typically occurs. The significance of the sequences is that the rocks were deposited contemporaneously but in different areas; they owe their present juxtaposition to major structural dislocations.

The presence of three sequences requires a threefold organization of stratigraphic description. The Lehigh Valley sequence is the longest ranging, most extensive, and most complete in this area, and provides the basic frame of reference. The Hamburg sequence is imperfectly known and is mapped in structural units characterized by distinctive lithologic assemblages. In most cases the ages of the constituent lithologies within the Hamburg sequence are indefinite, though no more recent observation supports Stose's (1946) inference of Cambrian as well as Ordovician age rocks. In its type area the Lebanon Valley sequence is quite comparable to the Lehigh Valley sequence, but the exposed section here is very fragmentary and occupies only a small part of the area. The summary discussion that follows is based largely on reference to correlative units in the Lehigh Valley sequence.

LEHIGH VALLEY SEQUENCE

The Lehigh Valley sequence was proposed by MacLachlan (1967) primarily to distinguish carbonate rocks of the eastern Great Valley of Pennsylvania from the somewhat different carbonate rocks of the Lebanon Valley sector. It comprises a Lower Cambrian basal quartzite and a large thickness of shallow-water Cambrian and Lower Ordovician limestone and dolomite that grades up into Middle Ordovician shale. The sequence was deposited on a basement of Precambrian gneisses which are now represented in the Reading Prong. The sequence is involved in several nappes in the Lehigh

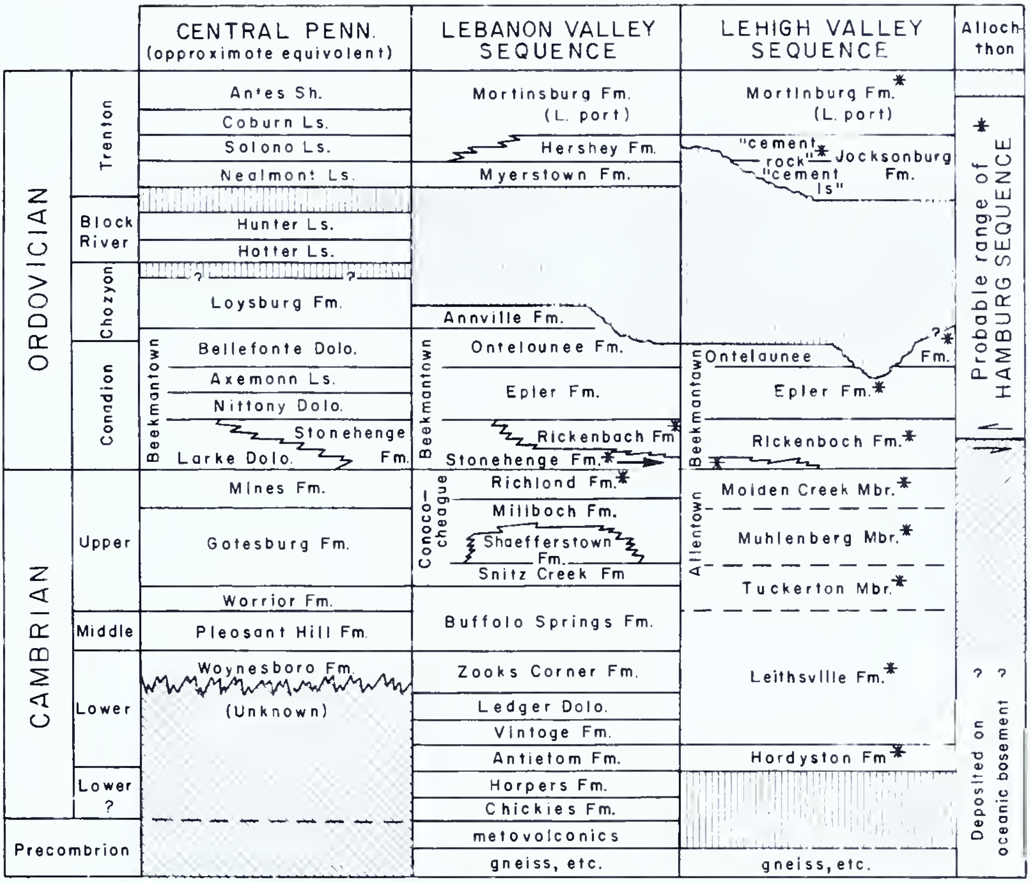

Figure 2. Correlation chart of stratigraphic sequences present in central Berks County and approximate equivalents of central Pennsylvania. The Lehigh Valley sequence is fully represented in the mapped area except for the "cement limestone" of the Jacksonburg Formation. The upper Lebanon Valley sequence is mostly structurally covered in the mapped area; rocks older than the Millbach Formation are not present owing to thrust relationships; rocks older than the Harpers Formation(?) are present only in the Conestoga Valley section of the northern Piedmont province. Asterisks designate units exposed in the mapped area.

Valley, but in the mapped area, it is essentially identified with the Irish Mountain nappe.

Precambrian

Mapping of the Precambrian rocks has been taken from Buckwalter (1962), who gives a detailed description and discussion of origins. His mapping has been modified only in the relocation of some faults and at several points around the margin of the Precambrian crystalline-rock area on the basis of drilling and foundation data obtained during mapping of the carbonate rocks.

About three quarters of the crystalline-rock area is underlain by granitic gneiss, which evidently formed in the episode of rock formation dated radiometrically as 1,000 million years bp (before present) and observed elsewhere in the Reading Prong from South Mountain in the Womelsdorf quadrangle eastward into New Jersey (MacLachlan and others, 1975). Younger ages from the Reading quadrangle just to the south (Lapham and Root, 1971) apparently represent argon loss. Much of the remaining crystalline-rock area is underlain by migmatites formed by injection and assimilation of older gneisses, which persist in relatively original form only in small, isolated remnants. All gradations are present in the migmatites, but they have been divided, for mapping purposes, into a number of arbitrary units based on apparent proportions of mineral admixture. Graphitic gneiss, quartz-biotite-feldspar gneiss, and probably most of the hornblende gneiss are metasediments. Granitic gneiss and pegmatite are believed to be in part "granitized" metasediments and in part locally igneous. Quartz-diorite gneiss is probably a migmatite.

Lower Paleozoic

Metadiabase

Metadiabase dikes are fairly common in the Precambrian terrane, especially in the Fleetwood quadrangle, though they appear only as float. The only large dike trends northeastward for about 1200 m (3900 ft) from about 1.6 km (1 mi) north of Angstadt Hill, and is about 15 m (50 ft) thick. The other dikes are much thinner and are frequently indicated by only a few float fragments. Most of these evidently strike northeastward but there is some variation.

The metadiabase is superficially similar to the Mesozoic diabase but can usually be distinguished even in hand specimen because of sericitization of the feldspar. Metamorphism is of a low-grade, retrograde type, clearly distinct from and younger than the metamorphism of the Precambrian gneiss.

Most metadiabase dikes in the Reading Prong are limited to crystalline-rock areas and are datable by field relationships only as younger than the late pegmatitic phase of the Precambrian metamorphism. A dike poorly exposed 1.2 to 1.7 km (approximately 1 mi) south of Lyons appears to be intruded into a fault offsetting the Hardyston Formation and may penetrate about 100 m (300 ft) into this Lower Cambrian quartzite. A more positively established penetration of the Lower Cambrian is found about 7 km (4 mi) to the east in the Boyertown quadrangle. Buckwalter (1962) noted the abrupt termination of two dikes in the Fleetwood quadrangle at the basal Cambrian contact, and inferred that these at least, and possibly most other occurrences, were of upper Precambrian age. The structural interpretation of this report, however, requires faulting at these places by criteria independent of the dike terminations. These dikes are then only necessarily older than the faulting, which is inferred to be Upper Paleozoic. More than one episode of pre-Triassic dike formation is possible, but it is not demonstrated by field relationships. The suggestion that these rocks are of the same age as the probable Ordovician diabase and basalt at Jonestown (which have similar initial and metamorphic petrology) can be traced back at least to Fraser (1937), and seems attractive here. It might even be suggested that this igneous episode correlates with the metabentonites that are extensively distributed in Lower Trenton (Middle Ordovician) sediments of Pennsylvania.

There is no obvious difference in the metamorphic character of the probable Paleozoic diabase in the Boyertown (15-minute) quadrangle to the east and in all other occurrences, which suggests that only one metamorphism is represented. This recrystallization is presumably related to a Late Paleozoic argon-loss event that is poorly defined in the Reading quadrangle just to the south (Lapham and Root, 1971, stations 37 and 38), and probably is a facet of the main Alleghanian orogeny. The dikes are thus apparently pre-Alleghanian, and are probably Lower Paleozoic on the basis of correlation to the metabentonite.

Cambrian System

Hardyston Formation

The Hardyston Formation rests nonconformably on the Precambrian crystalline rocks and contributes to forming the topographic upland of the Reading Prong. The mapping, with minor modification of some contacts with adjacent carbonate rocks, has been taken from Buckwalter (1961), who gives detailed descriptions and sections. The Hardyston-gneiss contact is exposed only in two places, but the basal conglomeratic member commonly forms ridge crests and can usually be traced without difficulty. The top is marked by an apparently abrupt change to dolomite, though the contact is nowhere exposed and is frequently a locus of thrusting owing to the contrast in rock competence.

Dense yellow-brown jasper appears to replace the upper Hardyston quartzite locally, and was long quarried by the Indians southeast of Lyons Station, but this material is much less abundant than it is in Lehigh County. The known occurrences in this area are in the vicinity of thrust faults, which may have localized the mineralization.

The rare exposures of the basal Hardyston contact shown about 1 foot (0.3 m) of grayish-green phyllite composed of sericite, crushed quartz, and some chlorite. Up to about 2-1/2 m (8 ft) of similar rock has been observed at this level in several places outside the mapped area, though it is apparently not everywhere present. Miller and others (1941) suppose that it is a metamorphosed relict soil developed on the gneiss, whereas Buckwalter (1961) attributes it to direct cataclasis of the underlying gneiss. In either case, it is obviously strongly sheared and reflects movement between the gneiss and quartzite during deformation. There is no evidence that such movement is of the magnitude of the major Paleozoic thrusts, but it may have been sufficient to shear out the basal conglomerate in those areas where the conglomerate is apparently missing. Such areas are indicated on the geologic map (Plate 1) by absence of the conglomerate symbol.

Buckwalter (1961) describes a section exposing 89 m (292 ft) of middle Hardyston down into the transition beds in a quarry at 40°02′N/75°05′W on the south side of the first ridge south of Irish Mountain. This is the best exposure in the mapped area, but it may also be observed in numerous other quarries. He estimates the total thickness to be about 180 m (600 ft), though it may thin somewhat eastward through the mapped area and is certainly thinner east of it. This thickness has been adopted for construction of cross sections throughout the area. It is presumed to be generally present below the gneiss in the Grings Hill thrust plate, because of the repetitions within the Prong, except where there are indications of shearing out along the thrust. Hardyston of less than full thickness is inferred from outcrop width and dip in the two ridges southeast of Irish Mountain along section A-A′. A well sited approximately on the gneiss contact at 40°26′08″N/75°51′46″W apparently penetrated the Hardyston Formation and the thrust; it passed into "limestone" at 56 m (180 ft), indicating a tectonically reduced thickness that may be encountered in this structural environment.

Walcott (1896) describes Lower Cambrian trilobites from the Reading quadrangle. These have not been confirmed by subsequent finds in the Hardyston Formation of Pennsylvania, but the Lower Cambrian age of the Hardyston has been firmly established in New Jersey (Palmer and Rozanov, 1976).

Leithsville Formation

The only exposure of the Leithsville Formation close to the Hardyston Formation is on the nose of Irish Mountain, where it is clearly very discordant to the Hardyston; drill records indicate imbricate thrusting in this area. Many large displacement thrusts are common at this stratigraphic level. Rare exposures to the east of the mapped area indicate an abrupt, but conformable, basal contact. Archaeocyathids recently discovered about 3 m (10 ft) above the contact near Franklin, N. J., have an age (Bonnia-Olenellus zones) well within the Early Cambrian according to Palmer and Rozanov (1976), who believe that a major unconformity within the Leithsville lies above the archaeocyathid beds. The top of the Leithsville was originally defined by the appearance of algal stromatolites in the overlying Allentown Formation in a dolomitic sequence not having other obvious distinguishing features. Aaron (1971) has studied this interval in detail and finds that the contact is transitional and is characterized by a change in nature of the depositional cycles that are present in both the Leithsville and the Allentown. The lower part of the Allentown Formation is lowest Upper Cambrian and most of the Leithsville is presumably Middle Cambrian.

Owing to its topographic position, exposures of the Leithsville are sparse. Miller and others (1941) provide descriptions of the closest extensive exposures (as "Tomstown" Formation), near the Lehigh River. The exposures reflect some lateral variation from the Leithsville type section along the Delaware River, but are generally consistent with the original description.

The upper part of the Leithsville Formation in this area is evidently more shaly than any described to the east and is apparently somewhat calcareous. Deeply weathered exposures of this lithology occur along the new bypass east of U. S. 222 north of Temple and evidently represent the lithotype that Stose and Jonas (1935) intended by "Elbrook Formation"; contrary to their mapping, upper Leithsville is not recognized south of the Tuckerton fault, nor between the Blandon and Fleetwood faults. Inclusion of these beds in the Leithsville is justified by their stratigraphic position, and is consistent with the original definition of the formation as occurring below the lowest recognized stromatolites. This lithology is suggestive of the Buffalo Springs Formation of the Lebanon Valley sequence, and apparently represents a lateral gradation toward that Middle Cambrian facies.

The only substantial exposure of typical Leithsville Formation is behind the mushroom house south of Dryville Road about 2.5 km (1.6 mi) east of Fleetwood. The float is definitely shaly from this locality to the Allentown Formation contact, and belongs to the upper shaly member of the formation. At this locality, silty- to shaly-chip soil grades down into about 2 m (7 ft) of dark-gray calcareous and dolomitic shale and silty shale, mostly thinly planar to wavy-laminated, but containing several apparently unlaminated bands a few centimeters thick. The base of the shale is marked by a dolomite-pebble conglomerate, about 20 cm (8 in.) thick, having a dark shaly matrix. This rock overlies a dolomite-pebble conglomerate having a sandy matrix, which grades down into a penecontemporaneous sharpstone conglomerate having a carbonate matrix. These form the top of 4.8 m (15.8 ft) of dolomite, apparently typical of the more variable parts of the Leithsville Formation. These variable lithologies include apparently structureless to thin and planar-laminated dolomite, festoon-laminated dolomite, oolitic dolomite, indistinct sharpstone conglomerate, and several dark-grayish-brown shale partings. Several beds have rosettes and blebs of pinkish to gray, mottled chert and there is a 5- to 13-cm (2- to 5-in.) bed of dark-gray chert. Both types of chert are sometimes recognized throughout the area of colluvial cover and are considered as diagnostic of a Leithsville substrate.

The thin planar-laminated dolomite is reported to be particularly characteristic of the formation to the east, where it may occur in beds up to 3 m (10 ft) thick.

The Leithsville Formation is not exposed in the Laurel Creek valley, but dolomite and chert recovered from beneath 40 feet (12 m) of Quaternary gravels in bridge-foundation borings are certainly related to those seen on the nose of Irish Mountain. The drilling was within an area shown as gneiss by Buckwalter (1961), and his mapping has been revised accordingly. As much as 30 m (100 ft) of Quaternary appears in water wells east of Deer Path Hill, and no exposure of the Leithsville occurs there within the mapped area. The formation is exposed not far south near the Reading City line in this structural belt.

Owing to almost complete cover, indications of complex internal structure, and thrust contacts with the Hardyston Formation, there is no objective basis for estimating the thickness of the Leithsville Formation in this area. Miller and others' (1941) Lehigh County estimate of about 1,000 feet (300 m) is used for construction of cross sections for this report, but the formation may well be somewhat thicker if the lithologic gradation toward the Lebanon Valley sequence implies an expansion to the thickness of the Middle Cambrian of that sequence.

Allentown Formation

The type Allentown Formation is a series of cyclical primary dolomites and dolomitized limestones of shallow-water to supratidal origin that contain numerous occurrences of algal stromatolites. Regionally it has gradational contacts to the underlying Leithsville Formation and the overlying Beekmantown Group. Neither contact is exposed within the mapped area, but the same general relationships seem to apply. For mapping purposes, it has been possible to distinguish three members of the Allentown that are defined and identified by the less soluble fragments in the residual soils. Exposure, especially of the lower part of the formation, is generally poor, but the bedrock stratigraphy of three members can be generally characterized. They have been traced throughout the main Great Valley belt of the Allentown Formation in Berks County, but it is questionable how much further east they may be useful. Aaron's (1971) data from western Northampton County suggest considerable parallelism to the Berks County sequence, but he did not consider the Allentown to be subdivisible for mapping purposes there.

Aaron (1971) characterizes the typical complete depositional cycle of the Allentown Formation as being composed of seven lithologies, shown in depositional order in Table 1. In Northampton County, all types are generally completely dolomitized, but only the uppermost dolomicrite (7) is a primary or penecontemporaneous dolomite. Dolomitization is less complete in central Berks County. Stromatolitic to oolitic rocks (6 to 4) are usually highly dolomitic; but the underlying detrital limestones, though predominantly magnesian, frequently contain sufficient calcite to react with dilute acid, and range to highly calcareous. The implication is that dolomitization was diagenetic within each cycle; the magnesium-charged water infiltrated from the supratidal dolomite zone and frequently had insufficient concentration or penetration to fully alter the lower part of the cycle.

Table 1. *Ideal Deposition Cycle in the Allentown Formation, Determined in Northampton County (Aaron, 1971)*

Rock type	Depositional environment
7. Dolomicrite	Supratidal
6. Algal stromatolite	Intertidal
5. Calcirudite	Intertidal
4. Oolitic calcarenite	Intertidal
3. Calcarenite	Intertidal
2. Calcilutite	Subtidal
1. Flat-pebble conglomerate	Subtidal or intertidal

The cycles are often incomplete and the constituent lithologies are developed in variable proportions. Through most of the Berks County section, calcilutite (2) and, to a lesser extent, calcarenite (3) lithologies predominate. Most commonly they are abundantly laminated with layers rich in terrigenous siliciclastics, usually silty but ranging from argillite to sand, which weather brown in contrast to the gray to grayish orange of the carbonate. Less commonly they are massive, or mottled and apparently bioturbated.

Some fossil debris but no identifiable fossil organisms are known in this area. In the Delaware River vicinity, a sparse faunule has established the top of the formation as uppermost Upper Cambrian, whereas lowermost Upper Cambrian (Dresbachian) has been established near the base. The Dresbachian faunule is not known to extend down into the underlying Leithsville Formation, which suggests that the base of the Allentown is somewhat older than the base of the Conococheague Group, its approximate correlative in the Lebanon Valley sequence and in south-central Pennsylvania.

The thickness of the Allentown Formation in this area is approximately 800 m (2,600 ft) based on partial sections and computations from the width of outcrop where there appears to be sufficient structural control. This value compares with about 520 m (1,700 ft) suggested in western Northampton County (Aaron, 1971). Geyer and others (1963) give the thickness of the approximately correlative Conococheague Group in eastern Lebanon County as 3,700+ feet (about 1,100 m). These rocks appear in the Lebanon Valley nappe and are separated by a major structural discontinuity from the Allentown Formation of the Irish Mountain nappe in the mapped area

(MacLachlan and others, 1975). The westward increase in thickness is accompanied by a loss of the light/dark-banded weathering character of the type Allentown so that typical exposures are superficially much like those of the Lebanon Valley sequence. No precise correlation has been established between the Conococheague Group formations of the Lebanon Valley and members of the Allentown Formation recognized in this area. There are many differences in detail as well as in the extent of overall dolomitization, but the increase in thickness does seem to be accompanied by some convergence toward the Lebanon Valley facies.

Soils over the formation as a whole tend to be characterized by variably abundant thin chips and occasional plates of grayish-yellow- to buff-weathered silty argillite and argillaceous siltstone which evidently had some original carbonate content. Such fragments are rare in Beekmantown Group soils and appear in reasonable abundance immediately below it, though the contact has usually been defined by other criteria. They are particularly abundant over the lower part of the formation, and there is some suggestion that the increase may be roughly gradational. Such increase in clastic content is consistent with gradation into the Leithsville Formation, but this concealed contact seems to be fairly well defined by an abrupt decrease in the proportion of the coarser grain sizes and probable amount of original carbonate in these residual fragments, and additional increase in the total clastic content as reflected by the proportion of shaly chips in the soil.

Tuckerton Member. The village of Tuckerton is on Pa. Route 61 in the south-central part of the Temple quadrangle and is the type area of the lowest member of the Allentown Formation in this vicinity. Bedrock lithology is characterized on the basis of about 40 exposures, many of poor quality, and none showing more than 6 m (20 ft) of section. Excavation for a gas line of large diameter that crosses the outcrop belt about 800 m (1/2 mi) southeast of Berkley exposed, beneath a thick soil, more than a meter (3 ft) of gray to yellowish, punky rock from which most of the original carbonate was leached. Much thinner transitions between soil and fresh rock are typically encountered over other carbonate units of this area, and this unusual depth of weathering probably accounts for the poor exposure of the Tuckerton Member.

The Tuckerton Member is defined for mapping purposes as comprising the belt not having superficially obvious soil characteristics lying between the sandy float of the Muhlenberg Member and the very shaly float of the upper Leithsville Formation. A bed or zone about 3 m (10 ft) thick of a distinctive orange to brown, apparently massive, argillaceous, very porous siltstone which apparently contained some original carbonate has not been identified in fresh exposures, but it makes a fairly persistent float zone immediately below sandy float of the Muhlenberg Member in the Temple quadrangle. This is considered the uppermost bed of the Tuckerton Member where present, but it was tentatively identified at only a few places in the Fleetwood quadrangle. Silty to occasionally sandy, somewhat porous shale chips are particularly abundant in float above the Tuckerton Member and imply a relatively large terrigenous clastic component. They have not been distinguished from similar residuum higher in the Allentown, but present sufficient differences in lithology and abundance with respect to the shalier upper Leithsville Formation to permit reasonable differentiation of the two formations.

Carbonate float fragments derived from the Tuckerton are generally very sparse. Limestone is considerably more common than dolomite, and is almost always medium light gray to light gray on fresh surfaces in contrast to the darker shades more characteristic of the higher members. Fragments of silicified cryptozoon beds (stromatolites) are rare but widely distributed as a distinctive black chert, which sometimes has a thin neutral-gray weathering film but is often quite fresh looking. This chert apparently occurs sporadically throughout the Tuckerton Member on the basis of float, but it is exposed only near the top at the Schuylkill River. It is apparently limited to, thus diagnostic of, the Tuckerton Member, and confirms prevalence of cryptozoa through this part of the Allentown Formation.

Scattered exposures indicate that all lithologies of the Allentown cycle (Table 1) are present. Stromatolitic and oolitic beds are present in a substantial proportion of exposures, which suggests a higher abundance than in the overlying rock. Siliciclastic laminae are frequently quite prominent in the detrital carbonate beds and often give rise to a thin-bedded aspect on weathering, though the contacts between distinctive lithologies and the principal parting units are spaced from about 20 cm (8 in.) to 1 m (40 in.).

From the width of outcrop, where some structural control is available and the position of both contacts seems fairly well fixed, the Tuckerton Member is calculated to be approximately 150 to 180 m (500 to 600 ft) thick.

Muhlenberg Member. Muhlenberg Township occupies most of the southern part of the Temple quadrangle east of the Schuylkill River. A substantial part of this township is underlain by the middle member of the Allentown Formation, which is herein named the Muhlenberg Member. The general lithology is well exposed at the Temple quarry of Berks Products Corporation (Muhlenberg Township), and at several large abandoned workings in the vicinity. The upper part is exposed in contact with the overlying Maiden Creek Member along the railroad 1.2 km (3,900 ft) south of the crossing at Rickenbach. The upper contact is placed to include a zone of several grayish-yellow-green shale beds up to 3 m (10 ft) thick; this is the thickest of known shale occurrences in the Allentown Formation of this area. The zone is not exposed elsewhere; but it is apparently persistent or recurrent, as an abundance of shale fragments is often encountered in the vicinity of the contact across the mapped area. Beds of similar shale up to about 1/2 m (1-1/2 ft) thick occur both higher and lower in the section, so the occurrence of such fragments is not diagnostic by itself. The lower contact of the Muhlenberg may be exposed in the bluff of the Schuylkill River east of the railway section, but access is difficult and it has not been precisely identified. It is well marked by the brown siltstone at the top of the Tuckerton Member in the Muhlenberg area.

The Muhlenberg Member is defined for mapping purposes as comprising the belt containing abundant sandy fragments in the soil; chert is generally sparse or absent. Sandy fragments are of two types. One is usually fairly coarse grained in blocky to sometimes rounded, equant fragments usually less than 5 cm (2 in.) but sometimes over 15 cm (6 in.) in diameter. These are derived from discrete calcareous/dolomitic sandstone beds up to 1-1/2 m (5 ft) thick that are exposed at several different stratigraphic levels in the Muhlenberg area, but individual beds cannot be established as being continuous along strike for any substantial distance. Fragments of this type are present in the Fleetwood quadrangle, though they are less abundant than in the type area. Such material becomes conspicuous again, however, to the east near the Lehigh County line. Less conspicuous, but more persistent, is a second sandy fragment type that is finer grained, typically has a platy to flattened ellipsoidal shape, and rarely exceeds 3 cm (about 1-1/2 in.). These are evidently derived from sandy laminae in the carbonates. Similar chips are sometimes found in the Tuckerton Member soils, especially in the lower part, but they are much more abundant in the Muhlenberg. Exposures of the overlying Maiden Creek Member suggest the possibility of such fragments at this level also, but sandy laminae here are apparently too carbonate rich to provide coherent fragments on weathering.

The contact based on sandy float of the Muhlenberg and cherty float of the Maiden Creek Member is usually distinct and can be located with fair precision. From the neighborhood of the Fleetwood fault and eastward, however, secondary silicification gives rise to dark-gray, rusty-filmed chert fragments that cannot be distinguished with confidence from typical chert of the Maiden Creek Member. The secondary silicification is apparently associated with limonite deposits that produce areas of abundant limonite soil fragments in the eastern part of this mapped area, and is sporadic but apparently has a wide stratigraphic range. For this reason the presence of chert is not considered to have clear stratigraphic significance if encountered in proximity to limonitic float. The presence of the secondary chert, however, presents practical mapping problems only with respect to the Muhlenberg-Maiden Creek contact. In such areas, the contact is selected primarily on the basis of the highest sandy float fragments. Secondary criteria are frequent occurrences of shale float, which seem to correspond to the shale zone of the railway exposure south of Rickenbach, and slight differences in the predominant lithologies of the carbonate float.

Carbonate float fragments are often fairly abundant from the Muhlenberg Member in contrast to the Tuckerton Member, but the Muhlenberg does not differ from the Maiden Creek Member in this respect. The most abundant carbonate fragments are light gray to yellowish gray weathered and have distinct brown laminae. The fragments are typically medium gray to medium light gray on fresh fracture surfaces. They are primarily fine grained, being derived from the calcilutite facies (2)(Table 1), but also from the pelletoidal rocks of the calcarenite facies (3). Generally similar float predominates in the Maiden Creek Member, but it frequently has a somewhat brownish weathering cast, and generally is slightly darker on a fresh surface. Fragments are only rarely highly calcareous, but a perceptible reaction to dilute HCl is usual in the Muhlenberg fragments and less common in the Maiden Creek fragments. Less abundant fragments represent all other lithologies of the Allentown cycle except the pebble conglomerate (1), which is, however, occasionally identifiable in Maiden Creek float. Among less abundant float types the differences between the Muhlenberg and Maiden Creek appear to be: stromatolitic, oolitic, and pelletoidal calcarenite, in order of increasing abundance, are present in the Muhlenberg Member, but rare to absent in the Maiden Creek; and massive to faintly laminated dolomite is rare in the Muhlenberg, but sometimes fairly common in the Maiden Creek Member.

With the notable exception of the quarries between U. S. Route 222 and Pa. Route 61 southwest of Temple, extensive exposures of the Muhlenberg Member are not common, though smaller exposures are widely distributed. Many of the smaller exposures cannot be distinguished with confidence from comparable exposures of the Maiden Creek Member except by their occurrence in the sandy float belt. With the occasional exception of exposures of the sandstone beds and some quite abundantly stromatolitic exposures, notable where Pa. Route 61 crosses the outcrop belt, most exposures could be substantially replicated by some portion of the Maiden Creek Member as exposed in the railway cut south of Rickenbach. Sandy beds and thick, sparingly laminated to massive, pelletoidal calcarenite beds in the major exposures are distinctive. Several very thick beds of light-gray limestone are present in the upper part of the Muhlenberg Member in the Rickenbach railway cut and are observed several places to the south in the Reading 7-1/2-minute quadrangle, but they are not a conspicuous component of the float, and have not been distinguished in exposures east of the Schuylkill River. These beds suggest some westward lateral gradation toward the facies of the Millbach Formation of the Lebanon Valley sequence, which otherwise is the unit of the Conococheague Group least like its probable correlative in the Allentown Formation.

Taken as a whole, exposures suggest that the Muhlenberg Member is predominantly magnesian, though rarely strictly dolomite; it is significantly more calcareous, on the average, than the Maiden Creek. Oolitic and particularly stromatolitic beds are more abundant though not especially common. Chert is rare in Muhlenberg exposures, but occasional nodule horizons invalidate the presence of chert as strictly diagnostic of the Maiden Creek Member.

The thickness of the Muhlenberg Member has been calculated from the outcrop width to be about 240 m (800 ft), the probable error being about 10 percent.

Maiden Creek Member. The lower reaches of Maiden Creek from the Ontelaunee Reservoir to the Schuylkill River flow primarily on the upper member of the Allentown Formation, which is fairly well exposed at a number of places near the creek. These exposures are herein designated as the type section of the Maiden Creek Member. An obvious reference section having over 70 percent exposure lies about 610 to 1190 m (2000 to 3900 ft) along the Reading Railroad south of the grade crossing at Rickenbach. This section extends down into the upper part of the Muhlenberg Member and is separated from the type section of the Rickenbach Formation by a covered interval that is largely over the Stonehenge Formation.

The obvious diagnostic mapping criterion for the Maiden Creek Member is the presence of small fragments of dark-gray to nearly black, structureless chert that has a brownish cast on weathered surfaces and, in places, a thin brown weathering rind. The fragments are frequently abundant in the soil. As noted in the previous section, these may be confused with stratigraphically less restricted cherts found in association with limonite concentrations in the eastern part of the mapped area, but are otherwise distinctive. The fresh color of the chert is not obviously different from that of chert found at various levels from the Ontelaunee to Leithsville Formations, but the brownish cast and the small average size of the fragments, which rarely exceeds 5 cm (2 in.), are generally unique to the Maiden Creek Member. They are not present in higher formations, and are very sparse to absent in lower parts of the Allentown Formation. The source of the chert is obvious in nodules, stringers, and thin bands of similarly weathering chert in a number of Maiden Creek exposures, but the abundance in the soil as compared to the abundance in outcrop requires that the residuum of a large thickness of dissolved carbonate be represented in the soil. Chert represents less than 0.5 percent of the member, as exposed in the Rickenbach cut.

Magnesian limestone and dolomite float fragments are common in many areas. They are predominantly light gray to brownish gray and have brown laminae on weathered surfaces, and are medium gray to medium dark gray on fresh surfaces. They are most commonly of the calcilutite lithology (2) of the Allentown cycle (Table 1), though all lithotypes except stromatolitic (6) have been recognized. The fragments are marginally distinguishable from carbonate float of the Muhlenberg Member by the criteria discussed in the prior section, but are quite distinct from the highly calcareous limestone fragments that sometimes appear in soils developed on the overlying Stonehenge Formation. This contrast, and the general absence of chert in Stonehenge soils, makes the upper contact of the Maiden Creek usually easy to define throughout the mapped area.

The railway cut south of Rickenbach is computed to traverse the 375-m (1,230-ft) total thickness of the Maiden Creek Member, of which the top 69.7 m (229 ft) is mostly concealed. The lower 305.4 m (1,002 ft) is about 85 percent exposed. This thickness is consistent with outcrop width and dips throughout the mapped area and has been adopted for structural interpretation. Twelve identified faults and a number of other possible faults within the section, however, indicate the measurements provide only an estimate of the actual stratigraphic thickness. No repetition of beds associated with faulting was recognized; cutouts of strata by strike-slip movement were evident in some cases, suggesting that the measured section is a minimum estimate of original stratigraphic thickness.

The chert that characterizes the Maiden Creek Member overburden constitutes a very minor portion of the total exposure in the railroad cut, but is widely distributed through the section. It is present in float above the upper covered interval and in the uppermost 30 m (100 ft) of exposure. The longest interval that does not have recorded chert is 51 m (168 ft) thick, underlying the uppermost exposures. Chert is generally more abundant in the lower part of the section.

All lithotypes of Aaron's (1971) cycle (Table 1) are present in this section, but cycles are rarely complete and sometimes show reversals, and the lithologies may occur in aberrant order. At some levels, small-scale (generally less than 10 cm, or 4 in.) erosional channeling is common at contacts between units of any lithotype. Laminated detrital carbonates, usually more or less thoroughly dolomitized, predominate in the section. Other lithotypes occur in variable proportions. The presence of only four definite stromatolitic beds confined to the upper part of the section, and one questionable occurrence in the middle, make this substantially the rarest lithotype. Oolitic beds are more abundant and widely distributed but are common only in association with the stromatolites and in a restricted zone in the middle of the formation. Quartz sand is abundant and occurs as a subordinant constituent (floating grains) in many calcarenite and some oolitic beds, and is concentrated in siliciclastic laminae. A variant that is apparently distinctive of this member is a number of calcirudite beds having a very quartzose calcarenite matrix which weathers to a rich brown.

The color of fresh rock in the Maiden Creek ranges from dark gray to medium light gray, but medium-gray to medium-dark-gray colors predominate, and the rock is somewhat darker than lower members on the average. Stratification and lamination of weathered rock is usually distinctly marked by color variation; the range is from light gray to yellow and brown, and grayish-yellow and brownish-gray hues predominate.

Ordovician System

Beekmantown Group

The name Beekmantown is widely applied to Lower Ordovician carbonate rock in the Appalachians, though there is some evidence that lowest Middle Ordovician may also be included in parts of southeastern Pennsylvania (MacLachlan and others, 1975). Hobson (1957, 1963) separated four formations in section on and near the Schuylkill River in the Temple quadrangle and just to the south in the Reading quadrangle. His mapping, as shown in part on the 1960 Geologic Map of Pennsylvania (Gray and others, 1960), is quite accurate near the Schuylkill River in the Temple quadrangle, but shows the defects of its reconnaissance character as it is carried further from his formational type sections. The four units he recognized, ranging from Stonehenge Formation (limestone) at the base through Rickenbach Formation (dolomite) and Epler Formation (limestone and dolomite) to Ontelaunee Formation (predominantly dolomite) at the top, are widely distributed in the Lebanon and Lehigh Valleys, but the Stonehenge is not known far east of this report area, and thickens considerably to the west at the expense of the Rickenbach, which it replaces. All units persist through the Great Valley in this mapped area, and the total thickness probably does not deviate much from the 712 m (2,335 ft) calculated by Hobson in the Schuylkill River vicinity.

An indefinite thickness of generally similar dolomite and limestone very poorly exposed in the northern Oley Valley (southeastern part of this mapped area) generally resembles the rocks of the Great Valley exposures but cannot be assigned with confidence to any of the formations recognized there. These rocks have been mapped as Beekmantown Group undifferentiated. They appear bounded by fault contacts with Precambrian gneisses, the Allentown Formation, the Jacksonburg Formation, the Martinsburg Formation, and the Hamburg sequence. They are also overlain in some areas by the Martinsburg Formation, but it seems probable that this is also a thrust-contact relationship. These rocks presumably belong to the Lehigh Valley sequence, and their emplacement is inferred to be related to development of the Irish Mountain nappe. They appear at a higher structural level, however, and may be part of a separately definable structural unit.

Some change in depositional environments, most notably marked by a change from dolomitizing conditions to the deposition and preservation of calcareous limestones in the western part of the Lehigh Valley sequence and in the Lebanon Valley sequence, apparently coincides with the poorly defined Cambro-Ordovician faunal boundary. A substantial hiatus showing some erosion separates the Beekmantown of the Lehigh Valley sequence from the Jacksonburg Formation. Middle Ordovician high-calcium limestone of the Annville Formation overlies the Beekmantown of the Lebanon Valley sequence without apparent disconformity but shows evidence of erosion prior to deposition of overlying rocks in the Oley Valley.

Stonehenge Formation. The name Stonehenge was imported by Hobson (1957, 1963) from the Cumberland Valley; the beds of Berks County are judged by Hobson to be in part equivalent to the lower, Stoufferstown Member of the type area. The latter, however, has been raised to formational status so that the Stonehenge of the two areas is probably not exactly correlative. The reference section for the eastern Pennsylvania usage is along the Schuylkill River at Glenside in the Reading quadrangle.

Hobson found the base of the Stonehenge to be essentially undefinable because it everywhere occurs in a broad covered interval, though the field contact between the Maiden Creek Member and the Stonehenge Formation can usually be traced by the disappearance of the characteristic Maiden Creek chert float. Regional evidence suggests that the contact is gradational. The exact position of the Cambrian-Ordovician boundary is not well defined by faunal evidence, but it certainly lies not far from the lithologic boundary, where it is placed for formal mapping purposes. The upper contact of the Stonehenge is placed at the base of the first thick crystalline dolomite bed in a transitional sequence which is affected by secondary dolomitization and therefore is not necessarily at a persistent stratigraphic level.

The dominant Stonehenge lithology is medium-light-gray to medium-gray, finely crystalline limestone having dark silty and siliceous laminae and subordinate beds of orange- to buff-weathering, irregular dolomitic laminae and mottling. Sharpstone conglomerate and fossil-fragmental calcarenite beds and lenses are less frequently encountered. Dolomitic beds are sparse in limited exposures in the Temple quadrangle but occur in the Kirbyville quarry and apparently increase in abundance eastward, so that they represent about 25 percent of the section in a quarry south of Kutztown less than 3 km (2 mi) on strike beyond the limit of the mapped area. Hobson divided his reference section into three members, but they have not been traced through the limited exposures of this mapped area. The Stonehenge Formation is essentially devoid of chert, and, as the units above and below carry distinctive cherts, it can be traced with fair confidence, although through much of its extent only very sparse carbonate fragments in the soil aid in its definition.

Hobson calculated 76 m (250 ft) of the Stonehenge Formation at the Glenside reference section about 2 miles (3 km) south of the Temple-Fleetwood area; 25 to 30 m (80 to 100 ft) probably account for all exposures south of Kutztown just beyond the north margin of this mapped area. The northeastward increase in interbedded dolomite apparently represents a primary facies change; however, a lowering of the Rickenbach secondary dolomitization level may account in part for the thinning. The formation is last recognized about 6 km (4 mi) east of Kutztown, where it disappears by thrusting under the Martinsburg Formation. It is not recognized several kilometers east of this point, where the interval is again exposed.

Rickenbach Formation. Hobson (1957, 1963) gives the name Rickenbach Formation to exposures, located along the Reading Railroad just south of Rickenbach Station in the Temple quadrangle, of dolomites and interbedded cherts overlying the Stonehenge Formation and underlying interbedded limestone and dolomite of the Epler Formation. The lower contact is apparently transitional and is controlled in part by secondary dolomitization. The upper contact is depositionally gradational and is best exposed along the Schuylkill River upstream from the Reading Boat Club.

Hobson divides the formation into two members, which are probably valid throughout the mapped area and might well be mappable under better exposure conditions. The lower member, which is best exposed at the Rickenbach Station section, consists of medium-gray to dark-gray, medium- to coarsely crystalline dolomite. It is somewhat calcareous and weathers to a light-gray color and a spotty, rough texture. There are subordinate beds of finer grained, yellowish-weathering dolomite and medium-grayish-yellow, mottled, partially dolomitized limestone. The finer grained, locally laminated, dolomites may be of primary origin, but the majority seem to be the result of secondary dolomitization. Mottled light-gray chert is sometimes present as rosettes and small masses in exposed sections and appears in sufficient abundance in float to be a useful mapping marker.

The type section for the upper member is continuous with the Epler Formation type section along the Schuylkill River just below Felix Dam. In general, the upper member is composed of medium-gray to medium-light-gray, finely crystalline, laminated dolomite, which may well be primary, and dark chert nodules, stringers, and beds. Much of the dolomite is gray weathering, in contrast to the distinctly yellowish-weathering dolomites of the Epler and Ontelaunee. A 28-m (90-ft) zone of beds containing well-rounded quartz sand is apparent in the upper half of the type section, but sandy dolomite is not a conspicuous constituent of other exposures or float. Medium-gray to dark-gray, mottled chert weathering to a rough, rather porous looking, often reddish-stained surface is not well exposed, but forms conspicuous and abundant float in the western part of the mapped area.

Hobson computes 171 m (560 ft) of Rickenbach Formation at his type sections near the Schuylkill River, which are the best exposures in the area. It apparently thickens eastward, approximately in proportion to the thinning of the Stonehenge Formation.

Epler Formation. Hobson (1957, 1963) places the type section of the Epler Formation at Felix Dam on the Schuylkill River about 1.4 km (0.9 mi) southeast of Epler Church, for which the formation is named. The base is defined by the lowest prominent limestone bed in an interbedded limestone and dolomite sequence that becomes increasingly dolomitic toward the base. Hobson places the upper contact at the highest limestone bed beneath a prominent zone of chert beds in the lower Ontelaunee Formation. For mapping purposes the chert itself is a much more useful criterion. Though the base of the Ontelaunee Formation is quite dolomitic, in some areas this formation apparently contains more Epler-like limestone than is apparent from the described sections, and the highest limestone is not an easily used criterion in tracing float. In areas where the chert is not well developed, however, the contact can often be defined with fair precision by a marked and fairly abrupt change in the proportion of limestone and dolomite float fragments.

The characteristic lithologies of the Epler Formation are thick beds of limestone interbedded with a smaller proportion of dolomite. The limestone is medium gray to medium dark gray and predominantly very finely crystalline to sometimes medium crystalline. It weathers light gray and has conspicuous yellow-weathering dolomitic mottling or, less frequently, lamination. The dolomite is yellowish weathering, finely crystalline, and laminated. Predominantly limy, sharpstone conglomerate, fossil-fragmental calcarenites, and occasional oolites are widespread but less abundant. Throughout most of the section, the limestone and dolomite are interbedded in tidal to supratidal cycles. Hobson recognizes at least 16 clearly defined cycles in his type section that grade upward from fragmental limestone to dolomite-mottled limestone, into laminated, apparently algal mat dolomites at the top. This mode of deposition appears to have been characteristic of most of the formation and accounts for the typical interbedded character. A 40-m (130-ft) zone just over 30 m (100 ft) below the top of the type section is only very sparingly dolomitic and contains a more conspicuous proportion of coarser fragmental limestones. This zone evidently extends across the mapped area and was the principal quarry stone at Rickenbach, south of Leesport, and near Moselem Springs.

Hobson measured 243 m (798 ft) of the Epler Formation at the type section, and his data indicate it might thin slightly from west to east. The mapped Epler includes some beds below the Ontelaunee cherts, which makes the unit correspondingly a little thicker; a thickness of 245 m (800 ft) seems a reasonable approximation for the area as a whole.

The best exposures are found at the type section on the Schuylkill River, along the south shore of Lake Ontelaunee, and in the quarries that are fairly common along strike, though many of these are small and debris filled.

Ontelaunee Formation. The type section of the Ontelaunee Formation (Hobson, 1957, 1963) is along the Schuylkill River southeast of Leesport, extending southeastward from the synclinal outlier of the Jacksonburg Formation and lying in Ontelaunee Township, from which it takes its name. Primary dolomites associated with chert are apparently the source of the magnesian water that dolomitized underlying limestones, making the contact gradational and diffuse, though the dolomitized zone is not as thick as in the lower Rickenbach Formation. The contact beneath the lower Ontelaunee chert zone is usually distinct for mapping purposes. The Ontelaunee Formation is disconformably in contact with the Jacksonburg Formation at the type section, but elsewhere in the mapped area the upper limit is everywhere apparently defined by structural discontinuities.

The Ontelaunee Formation is primarily dolomite, though it may contain a greater proportion of limy beds in some areas than is apparent in Hobson's described sections. Hobson identifies three members, the lowest containing beds of dark-gray chert up to several feet thick; the middle member consisting almost exclusively of even, thick beds of thinly laminated dolomite containing dark-gray chert nodules in places; and an upper member in which the laminae are less prominent or absent and there is a minor proportion of interbedded limestone having dolomitic mottles or laminae. Generally, limestone float and interbeds are more conspicuous west of the Schuylkill River and especially southwest of the mapped area. Chert ranges through a larger portion of the exposed interval toward the east, but this may be only a consequence of a limited part of the formation being exposed against tectonic contacts rather than a stratigraphic rise in the position of the chert. Secondary silicification associated with the development of limonite deposits may also be a factor in the increased chert abundance.

Typical dolomites of the Ontelaunee Formation are very finely crystalline, medium dark gray, yellowish weathering, and finely laminated or often apparently structureless (especially in the upper part), and occur as 30- to 60-cm (1- to 2-ft) beds. In places, more coarsely crystalline dolomites, interbedded especially in the lower part of the section, are apparently dolomitized limestone. The general conditions of deposition seem to be similar to those of the Epler Formation, except the majority of beds were deposited under supratidal conditions comparable to the conditions that formed the upper part of the Epler cycles.

Hobson calculates 223 m (732 ft) of the Ontelaunee Formation along the Schuylkill River south of Leesport, which includes an estimated 29.6 m (97 ft) below chert exposures. Two-hundred meters (650 ft) seems a reasonable estimate for the maximum thickness of the formation as mapped in this report area. Through much of the area the upper limit of exposure is defined by tectonic contacts, and the exposed portion is clearly less than this thickness figure. The amount of relief that may have been produced by erosion during the post-Ontelaunee hiatus is difficult to evaluate under these conditions, but the Ontelaunee, though present in western New Jersey, is absent beneath the Jacksonburg Formation in parts of the eastern Lehigh Valley, apparently as a consequence of pre-Jacksonburg erosion.

The best exposures of the Ontelaunee Formation are along the Schuylkill River below Leesport and above the Epler Formation type section at Felix Dam. The formation may also be seen in quarries south of West Leesport and north of Moselem Springs.

Jacksonburg Formation

The Jacksonburg Formation is represented in this area only by the upper "cement rock" facies of the Lehigh-Northampton cement district. Bedding is usually obscure but apparently parallels bedding in the underlying Ontelaunee, where the basal contact is preserved in a synclinal outlier south of Leesport. A considerable depositional hiatus may exist at this horizon, and some erosion of Ontelaunee is probable from regional considerations, but no confirming details are derived from this exposure. Thrusting is prevalent at the base of discontinuous Jacksonburg exposures along the northwestern side of the main limestone valley. Similar rocks overlie Annville limestone in the Oley Valley, and are there questionably referred to as the Jacksonburg Formation following the practice of quarry operators in that district.

The upper contact of the Jacksonburg Formation is quite abruptly gradational into the Martinsburg Formation by rapid increase in shale content. Where penetrated by core drilling at the cement quarry at Evansville the contact can be visually picked to an inch (2.5 cm) by experienced workers. The base of the Martinsburg is invariably somewhat limy as a consequence of continuous gradational deposition.

The Jacksonburg Formation within the mapped area is everywhere apparently a very thickly but very obscurely bedded, strongly cleaved, very dark gray, argillaceous limestone. Typically, it has nearly ideal composition for the manufacture of portland cement, but may be too magnesian (over 5 percent $MgCO_3$) for this purpose in much of this area, which is at the extreme western end of the district noted for natural cement rock. The rock typically weathers to light-gray or buff plates or chips that are very similar to weathering products of the Martinsburg Formation and many of the shales in the Hamburg sequence. They can usually be distinguished, however, by retention of sufficient carbonate to produce a good reaction with hydrochloric acid, which is not characteristic of the overlying shales, even if they have appreciable original lime content.

Two thin beds of sticky, yellowish-weathering metabentonite (volcanic ash) appear about 9 and 12 m (30 and 40 ft) above the basal disconformity in the syncline south of Leesport and in the abandoned Vindicator quarry 1.4 km (0.9 mi) east of Evansville. Similar metabentonites occur in the Myerstown Formation of the Lebanon Valley sequence, and near the contact between "cement rock" and "cement limestone" in both units in the main part of the Lehigh-Northampton cement district. These beds represent fairly reliable time horizons and fix the base of the Jacksonburg in this area fairly closely. Probably not more than 50 m (150 ft) of Jacksonburg is preserved in the outlier south of Leesport. Possibly somewhat more is present in the neighborhood of the Evansville quarry, but bedding is obscure and structural repetitions, though probable, are not readily resolved. At Fogelsville, about 21 km (13 mi) northeast of Evansville, the "cement rock" is 120 m (400 ft) thick, and it thickens to nearly 280 m (900 ft) near the Delaware River. The additional thickness of "cement limestone" not represented in Berks County is not included in these figures. Extrapolation of this gradient would suggest about 90 m (300 ft) as the normal thickness for the report area, but no section is complete owing to structural complications.

The best exposures of the Jacksonburg occur in the Allentown Portland Cement Company quarry at Evansville. The Schuylkill River section below Leesport is the best place to examine relationships with underlying rocks.

R. L. Miller (1937) assigns the Jacksonburg Formation to the Lower to lower Middle Trenton Stage, correlating it to the Hull and Sherman Fall Formations of the old New York Standard section. Drake (personal communication) says recent conodont studies support a "Sherman Fall" age. Cooper (1956) reaches essentially the same conclusion based on brachiopod studies, but cites formations of other areas for most direct correlation. He assigns the unit to the upper Wilderness and lower Barneveldian Stages used in New York. The low stratigraphic position of the metabentonites south of Leesport suggests that only the upper part of the formation is present, and indicates that the hiatus above the Beekmantown Group represents a major portion of the Middle Ordovician.

Berry (1970) equates the Barneveld Stage with his zone 13 of the graptolite succession in the shaly facies of New York. This is undoubtedly younger than some rocks of the Hamburg sequence, which is significant in establishing the allochthonous character of the Hamburg rocks.

Martinsburg Formation

The name Martinsburg Formation has been widely applied throughout the Great Valley for shale or slate and associated rocks above the Cambrian to Middle Ordovician carbonate belt, though it has long been recognized that difficulties with this designation occurred in the area between the Susquehanna and Lehigh Rivers (Kay, 1941; Stose, 1946). Recent work in this area has established that a major portion of these rocks are allochthonous rocks of Taconic affinity (Alterman, 1971; Myers, in preparation; Root and MacLachlan, 1978; Wood and MacLachlan, 1978), which have been designated the Hamburg sequence (MacLachlan and others, 1975) following Stose.

True Martinsburg Formation definitely occurs in two limited parts of the report area. These dark-gray, often slightly calcareous slates belong to the lower Martinsburg Bushkill Member, and are gradational with the underlying Jacksonburg Formation. These occurrences lie north of the Jacksonburg in the vicinity of Evansville, and in the extreme southern part of the mapped area in the Oley Valley. All other occurrences of shales formerly called Martinsburg are related to the Hamburg sequence. Near Evansville, the Martinsburg is thrust beneath the Hamburg sequence in a tectonic contact that appears to be a relatively young feature.

Typical Martinsburg is a dark-gray clay slate in which bedding is sometimes discernible from thin silty laminae. It is frequently slightly calcareous, producing a very slight reaction with dilute hydrochloric acid. It weathers to cleavage plates that are yellow to buff, and often show a bedding trace; the plates are distinguished only with great difficulty from some weathered rock in the Hamburg sequence.

The Martinsburg Formation in this area is best exposed along the old railway extending up the east shore of Lake Ontelaunee from Evansville. The structure is obviously complex, though stratigraphic repetitions cannot be distinguished owing to the lack of any distinctive markers. No reliable estimate of the thickness can be made here, but it is considerably less than the several thousand feet of the Bushkill Member at its type section in Northampton County. Faunal evidence from that area would suggest that the exposures here are probably all of Trenton (Barneveld) age regardless of any questions that may concern the dating of higher parts of the Martinsburg Formation north and east of the mapped area.

LEBANON VALLEY SEQUENCE

Carbonate rocks of the Lebanon Valley, which lie in the Lebanon Valley nappe, were designated to make up the Lebanon Valley sequence (MacLachlan, 1967). This sequence has subsequently been recognized in the Conestoga Valley (Lancaster County) of the Piedmont province, where the section includes rocks older than the Middle Cambrian, which are the oldest exposed rocks in Lebanon County. Work in progress by the author in the Reading quadrangle shows the presence of Lower Cambrian rocks of Conestoga Valley affinity in the Great Valley and confirms the propriety of including these rocks in the Lebanon Valley sequence.

Only a small portion of the Lebanon Valley sequence is exposed in the mapped area, where it occurs along the southern margin at the northeastern limit of the Sinking Spring thrust plate (MacLachlan and others, 1975).

These rocks evidently belong to the upper limb of the Lebanon Valley nappe, although they are emplaced on a younger thrust. Projection of structures in the Reading quadrangle indicates that approximately the upper half of the sequence, extending from the lowest Martinsburg Formation into the Millbach Formation (Upper Cambrian), is present at the southern edge of the mapped area; but it is mostly concealed under a higher thrust plate. Only the Middle Ordovician and uppermost Cambrian appear at the surface.

The complete stratigraphic column for the Lebanon Valley sequence is shown in the correlation chart (Figure 2). The following comments are limited to the portion believed present in this area and are mainly directed to relationships with the Lehigh Valley sequence. More extended descriptions are provided by MacLachlan and others (1975) from exposures in the Sinking Spring quadrangle.

Cambrian System

Conococheague Group

Upper Cambrian rocks of the Lebanon Valley sequence approximately correlative to the Allentown Formation have been assigned to four formations in the Conococheague Group. Only the Richland and Millbach Formations of the upper part are known in the Sinking Spring thrust plate and are inferred to extend into this mapped area. The Conococheague resembles the Allentown Formation in being composed predominantly of cyclic shelf carbonates, but differs notably in the proportion of dolomitic rock and in many details. Exact correlation between the units of the two sequences is not possible, though the upper units are most similar. Structural projection from exposures in the Reading quadrangle indicates about 600 m (2,000 ft) of this group may be present in a thrust slice (level 2) in the subsurface along the southern margin of the area. Only a small part of the mapped area is directly underlain by these rocks, but there is no exposure.

Millbach Formation (Subsurface). In its type area in the lower limb of the Lebanon Valley nappe, the Millbach Formation comprises about 460 m (1,500 ft) of strata characterized by a predominance of light-gray to pink limestones at its closest exposure in the Womelsdorf quadrangle (Geyer and others, 1963). Exposures in the Sinking Spring and Reading quadrangles in the upper limb of the nappe suggest some convergence toward Allentown lithologies, but the Millbach remains the most distinctively different part of the Conococheague Group, of which it is the second highest formation. Projection of structure in the Reading quadrangle suggests that up to 100 m (300 ft) of the top of the formation is locally present beneath the gneiss of the Reading Hills.

Richland Formation. The Richland Formation is the uppermost Cambrian unit of the Lebanon Valley sequence and appears here in the upper plate of the Sinking Spring thrust. There is no adequate exposure of this unit, which is limited to a small tract east of Bernharts Hill, but it has been observed in temporary exposures at the Western Electric plant near the south border of the mapped area, and can be traced from there to its type area.

The Richland Formation is much like the approximately correlative Maiden Creek Member, except for the presence of coherent sandy beds such as appear in the Muhlenberg Member and the much less abundant chert. The formation is dominantly dolomitic and is easily distinguished from the overlying Stonehenge Formation and the underlying Millbach Formation, which are both more calcareous. Both contacts appear to be gradational and represent environmental change during continuing deposition.

The closest full section of the Richland Formation is estimated to be about 530 m (1,700 ft) in the Womelsdorf quadrangle (Geyer and others, 1963). The partial section underlying the area west of Bernharts Hill probably does not exceed 200 m (650 ft), but the bounding thrusts apparently cut across section and the full thickness is inferred to be locally present in the subsurface.

Ordovician System

Beekmantown Group (Subsurface)

The Beekmantown Group of the Lebanon Valley sequence at its closest described exposure in the western part of the Sinking Spring quadrangle (MacLachlan and others, 1975) has the same formations and is sufficiently like the Beekmantown of the LehighValley sequence of this area that a repeated description of the individual units is not warranted. Beekmantown of the Lebanon Valley sequence also appears in the Oley Valley not far south of the Fleetwood quadrangle, but, with the exception of a few quarries, it is very poorly known. For construction of the cross sections it is assumed that the formations of the Beekmantown Group have the same thicknesses as in the Lehigh Valley sequence.

The uppermost Ontelaunee Formation of the Beekmantown is certainly present in the Oley Valley, where it is overlain with apparent conformity by the lower Middle Ordovician Annville Formation. This succession is characteristic of the Lebanon Valley sequence and contrasts with the hiatus apparent in the Lehigh Valley sequence. The upper Ontelaunee beds are apparently younger than any part of the Beekmantown of the Lehigh Valley sequence in the mapped area.

Annville Formation

Exposures of the Ontelaunee Formation at the Eastern Industries quarry in the Oley Valley in the Birdsboro quadrangle are overlain by 0 to 34 m (0 to 110 ft) of wavy-bedded, light-gray weathering, high-calcium limestone of the Annville Formation. The lower contact is apparently conformable. Paleosolution features suggest much of the thickness variation may result from post-Annville erosion, but considerable shearing at the upper contact indicates structural factors may also be involved. A more uniform thickness of about 25 to 30 m (80 to 100 ft) bounded by sheared contacts in an overturned limb is exposed for several hundred meters along strike in the Allentown Portland Cement Company quarry to the east. Forty-one meters (130 ft) of the same rock in a drill hole about halfway between the Eastern Industries quarry and the Fleetwood quadrangle line confirms northward extension of these rocks in the subsurface. They are inferred to be present from sparse float and structural considerations in the upper plate of the Sinking Spring thrust (level D2a, Plate 2) in the extreme southeast part of the mapped area.

Jacksonburg Formation

Sheared rock above the upper contact in the Allentown Portland Cement Company quarry in the Birdsboro quadrangle appears similar to the "black rock" of the quarry footwalls in the Annville Formation quarry district of Lebanon County. It evidently represents the Myerstown Formation, which is usually in this position in the Lebanon Valley sequence, but characteristic Myerstown float has not been recognized. No Myerstown lithology is present at the Eastern Industries quarry, and the shaly limestones have been referred to the Jacksonburg Formation following the local usage of quarry operators. The lithology is correct, but the Jacksonburg of this area is indistinguishable from the Hershey Formation, which normally succeeds the Myerstown and Annville Formations in the Lebanon Valley sequence. An analysis from the southwestern Oley Valley (Gray, 1951) shows 5.49 percent $MgCO_3$. This is on the high side of the range for the Jacksonburg Formation and on the low side of the range for the Hershey Formation, but is consistent with either designation. If this analysis is representative of the Jacksonburg in the Oley Valley, the rock is not suitable for cement manufacture.

A drill hole south of the quadrangle line, started in the Martinsburg Formation, penetrated a total thickness of 30 m (100 ft) of Jacksonburg Formation. This is a relatively small thickness to account for the width of exposure in the southeast part of the mapped area, but the structure is complex, and it seems the most reliable thickness determination.

Martinsburg Formation

The youngest exposed rocks in the Sinking Spring thrust plate (level D2a, Plate 2) include a small thickness of the lowermost Martinsburg Formation. Exposure is very poor, but the rocks are apparently indistinguishable from lower Martinsburg of the Lehigh Valley sequence.

A maximum preserved thickness of less than 75 m (250 ft) of the Martinsburg Formation is estimated to occur in an isolated patch in the Birdsboro quadrangle. There is probably not more than half of this amount at its northern end in the mapped area.

HAMBURG SEQUENCE

A thrust complex of diverse, argillaceous to sandy, allochthonous rocks and associated subordinate limestones occupies the western and northwestern part of the mapped area and is present in slivers along the Sinking Spring thrust. The name Hamburg sequence from the Hamburg klippe of Stose (1946) was suggested for these rocks (MacLachlan and others, 1975), which are similar in structural position to, though apparently more restricted in age than, the Taconic sequence of New York and Vermont. Regional relations of these rocks are discussed by Root and MacLachlan (1978).

Rocks in this area east of the Schuylkill River were included in reconnaissance mapping by Alterman (1971). The present mapping differs considerably from that version, but revisions were made in consultation with Alterman, partly on the basis of new data she provided. Myers (in preparation) has studied this sequence in great detail in the Bernville quadrangle and has established a series of seven slices; each is characterized by a distinctive lithologic assemblage and constitutes a tectono-stratigraphic unit. Wood and MacLachlan (1978) have shown that these seven and an eighth higher unit are sufficient to organize the major lithic variations of the Hamburg sequence throughout Berks County, and they map them as lithotectonic units 1 to 8 in ascending order of superposition. The seven units of the Bernville quadrangle are fragmentarily present in the Temple-Fleetwood area and are designated by Wood and MacLachlan's nomenclature.

Present exposures of the Hamburg sequence in the mapped area are delimited by structures younger than the original emplacement of allochthonous rocks. In easternmost Berks and western Lehigh Counties the lowest unit was emplaced on medial and lower Martinsburg Formation along with associated wildflysch in an apparently semiconsolidated condition (Alterman, 1971), and represented the Taconic thrust of Stose (1946). This event marked the onset of the classic Taconic orogeny in this area. In northern Berks County, the Hamburg sequence lies unconformably below the Silurian Tuscarora Formation or locally, the Sharps Mountain Sandstone of Platt and others (1972), which is considered uppermost Ordovician Bald Eagle/Juniata Formations on the state geologic map presently in preparation (Berg and others).

Nappe development in the carbonate rock was evidently in progress during advance of the Hamburg sequence, but the lower units are believed to have been emplaced in the area of Martinsburg deposition prior to advance of nappes to their northwestern limit in this area (Root and MacLachlan, 1978). Emplacement of higher slices had more of a hardrock thrusting character (Alterman, 1971; Myers, in preparation) and may have extended into the early phase of carbonate tectonization in this area, which is also considered Taconic, though differing in style from the classical Taconic.

The age of Hamburg sequence rocks is not fully resolved. The only evidence within this mapped area comes from a graptolite faunule collected on the west side of the Schuylkill River near Shoemakersville about 0.5 km (0.3 mi) southeast of the quadrangle border along the railroad in lithotectonic unit 2, and identified as containing *Climacograptus* cf *C. eximius, Dicellograptus, Dicranograptus* sp., *Glyptograptus* cf. *G. teretiusculus,* and *Pseudoclimacograptus scharenbergi* by Berry (personal communication), who places it in zones 11-12, as old or older than the Jacksonburg Formation. Two additional collections northwest along the railroad a short distance into the Hamburg quadrangle may be somewhat younger. Berry assigned a zone 12 or 13 age to graptolites also from lithotectonic unit 2, and an age probably in the range of zone 11 to 13 from poorly preserved material in green silty rock of lithotectonic unit 4 or lithotectonic unit 2. These may range up to lower Martinsburg age. Additional collections in Berks County, apparently in lithotectonic units 1 and 2 (Myers, personal communication), were identified by Riva as coming from the *Nemagraptus gracillis* zone, or approximately zone 11 of Berry. The total faunal assemblage has a distinctly Normanskill aspect ranging up only to the age of the Black River Group; thus it is probably older than the Jacksonburg Formation.

A single collection by Gannis (data from Myers) near the Susquehanna River, placed in the *Didymograptus "bifidus"* zone by Riva, provides recent confirmation of the presence of Deepkill graptolites claimed in this area by Stose and Jonas (1927). This fauna is closely associated with one from the *N. gracillis* zone. The rocks having the older fauna apparently slid into the younger sediment during a later depositional event. Limestone blocks interpreted as slide-emplaced in lithotectonic unit 1 near Lenhartsville contain lower Arenigian conodonts (Bergstrom and others, 1972) that may be as old as Berry's graptolite zone 4 or 3. This limestone differs from the contemporaneous Beekmantown Group in being of deeper marine facies and having conodonts of Balto-Scandic aspect. Most of the more exotic rocks in the Hamburg sequence are undated, and the proportion of relatively old rocks may be greater than might be inferred from available dates. Very similar rocks of the Jutland klippe in New Jersey (Perissoratis and others, 1979) have an upper unit that has an age range comparable to most of the Hamburg sequence localities and an equally extensive lower unit ranging in age down to graptolite zone 2. Unlike the type Taconic sequence and contrary to the claim of Stose (1946), Cambrian rocks are apparently not present in the Hamburg sequence.

Lithotectonic Unit 1

The lowest lithotectonic unit is composed of thick-bedded, brown, brownish- or gray-weathering, calcareous graywacke interbedded with olive, gray-weathering siltstone and shale. Additional lithologies are encountered in the main outcrop belt north of the mapped area. Graywacke is abundant in the slice on the southeastern edge of the Hamburg sequence; finer grained rocks predominate in the patches in the northwest corner.

The base of this unit was described in general observations on the Hamburg sequence. Alterman (1971) equivocates on the significance of the upper contact; Myers (in preparation) apparently considers it depositional; Wood and MacLachlan (1978) provide the interpretation of thrusting shown here. The author believes the problem to be more semantic than physical. The relationship appears to be one of syndepositional(?) gravitational emplacement of lithotectonic unit 2 on lithotectonic unit 1, probably before emplacement of unit 1 on the Martinsburg Formation. Whether this constitutes thrusting or redeposition is essentially a matter of definitions.

Exposures within the mapped area do not necessarily represent any very great thickness, but the width and diversity of the main northern outcrop belt suggest a large though indefinite thickness, possibly on the order of 1 km (0.6 mi). This unit is inferred to compose nearly half of the allochthonous terrane extending from Cumberland County to Lehigh County.

Lithotectonic Unit 2

Wood and MacLachlan (1978) divide this lithotectonic unit into two parts on the basis of hydrologic properties apparently related primarily to the abundance of included limestone. The mappable limestone zones west of the Schuylkill River present an obvious contrast with the eastern side, but there are indications of calcareous zones to the east. Contrasts in associated lithologies within the Temple quadrangle do not appear to be as marked as implied by Wood and MacLachlan's general description for the county.

The predominant lithology is dark-gray shale to siltstone, having an olive or greenish cast in the coarser grained rocks; it is usually perceptibly sericitic and locally dolomitic or calcareous. Intercalated zones of light-gray-weathering, medium- to dark-gray ribbon limestones and limestone conglomerates having a shale matrix are more abundant toward the west; quartzose calcarenite occurs adjacent to a ribbon limestone at one locality, but is more common in this association in the Bernville quadrangle. These limestones may not be entirely indigenous to, nor contemporaneous with, the shales.

Lithotectonic Unit 3

A slice of interbedded red or maroon, and olive, coarsely micaceous siltstone probably not more than 50 m (160 ft) thick is intercalated in the thrust separating lithotectonic units 2 and 4 near Pa. Route 61. This isolated slice is the easternmost exposure of a unit more extensively developed at this level to the west of the area. Alterman's (1971) description of her unit that is approximately equivalent to lithotectonic unit 4 as being locally red is apparently based solely on the inclusion of this slice.

Lithotectonic Unit 4

Thick to massive bedded, greenish-gray silty shale and micaceous siltstone characterize the unit most extensive in this area. Limestone zones, poorly exposed east of the Schuylkill River, except for the Onyx Cave-Crystal Cave belt north of the mapped area, increase in abundance westward. Abundant outcrops in the Bernville quadrangle show a variety of limestones, including the two types observed west of Leesport. Here the inner belt is composed of thin-bedded calcilutite containing dark shale partings or thin interbeds. The outer belt is a very quartzose calcarenite, quite dolomitic at the north end, and apparently more calcareous and cavernous to the south. Both of these lithologies are included in the "Leesport Formation" type section. A zone having a matrix typical of lithotectonic unit 4 but containing some graywacke and phyllitic limestone beds at the north end of Lake Ontelaunee is distinguished as unit 4a. It is apparently unique to this area and may represent a distinct thrust or slide slice. Slide emplacement of the diverse and somewhat discontinuous limestone zones during the deposition of the siltstone of unit 4 also seems likely.

The north edge of the outcrop belt of lithotectonic unit 4 in this area shows thrusting on unit 2 and a local slice of unit 3. On the southern edge it is thrust on unit 1, and unit 2 is apparently cut out in between. This relationship is also quite prevalent east and north of the area with the implication that the unit 4 slice was originally somewhat more extensive than the unit 2.

The sequence unit 4/unit 5 is not exposed in the Temple quadrangle as a consequence of younger structures. It does appear in the Bernville quadrangle.

Lithotectonic Unit 5

Purple, green, and tan shales are exposed beneath lithotectonic unit 6 in a slice west of Rickenbach (exposed by Texas Eastern Gas pipeline construction) and in the southwest corner of the area, where they are thrust on the Beekmantown. These are the easternmost exposures of this relatively restricted lithotectonic unit, which terminates westward in the Bernville quadrangle.

Lithotectonic Unit 6

This unit contains greenish-brown siltstone, claystone, and shale, sometimes perceptibly sericitic, and in places contains interbeds of quartz-pebble graywacke conglomerate and some graywacke. Limestone beds are not definitely known in the area but appear locally to the west. The quartz-pebble conglomerate is rarely exposed but makes abundant float on ridge crests.

The shale of the Hyde Park belt does not contain the distinctive conglomerate, but it is considered to be of unit 6 affinity on the basis of a local slice of purple shale, apparently unit 5, beneath it in the Reading quadrangle, and general similarity to the finer grained rocks of unit 6.

Lithotectonic Unit 7

This unit comprises olive-weathering gray shale and siltstone and maroon shale, and minor beds of fine-grained brown sandstone. It is thrust on lithotectonic units 6, 4, and 2 in this area. This relationship persists westward, where unit 7 has also been observed in contact with unit 3. This highest lithotectonic unit evidently arrived late in the evolution of the Hamburg sequence when the lower units had become somewhat deformed during the development of the carbonate nappes.

"LEESPORT FORMATION"

Stose and Jonas (1927) proposed the name Leesport Formation for Middle Ordovician limestones from the exposures along the railroad at West Leesport. The status of this formation, which is no longer in current use, was summarized by MacLachlan (1967). As the type section lies in the mapped area and the present mapping makes this complex section more explicable, it should be noted that "Leesport" is herein abandoned. The West Leesport section displays imbricate slices in the Leinbachs thrust zone. The calcareous portions of this section include both the Jacksonburg Formation and two types of limestone from lithotectonic unit 4.

POST-OROGENIC ROCKS

Jurassic System(?)—Diabase

A single dike of dark-gray, fresh, fine- to medium-grained diabase is about 5 m (16 ft) thick at an exposure in the west bank of the Schuylkill River above Felix Dam. It has been traced primarily on the basis of float about 10.4 km (6.5 mi) southwestward from the vicinity of Tuckerton into the Sinking Spring quadrangle.

This diabase seems clearly related to similar rock intruding upper Triassic sediments to the south. The igneous rocks have traditionally been considered Triassic, but recent work in paleomagnetism (deBoer, 1967) and detailed paleoflora studies (Cornet, 1977) indicate that the uppermost Newark Series in the Birdsboro quadrangle, and its associated lava presumably related to the intrusives, may be Early Jurassic.

Cenozoic Deposits

Terrace Gravels

Rounded pebbles and some cobbles of several Silurian and younger Paleozoic formations derived from the mountains to the north of Berks County are patchily distributed beside the Schuylkill River and locally extend as much as 30 m (100 ft) above it. They are deposits of high flow in the Schuylkill, probably associated with an extreme climatic event of the Pleistocene. Boulders of Tuscarora quartzite, some exceeding 1½ m (5 ft) in length, are found at the base near Shoemakersville. These appear to be in a discrete size class and were probably transported by local ice rafting.

The gravel deposits are often thin, as evidenced by scattered bedrock exposures that protrude through the gravel, but they may reach at least 6 m (20 ft), as was encountered in the excavation for the water tower 1.6 km (1 mi) west of Tuckerton.

Colluvium

Gravelly silt containing abundant pebbles, cobbles, and some boulders of quartzite and subordinate gneiss forms an extensive blanket over carbonate rocks around the Reading Hills. Active movement of this material in extreme climatic events is demonstrated by the channeling and redistribution apparent after Hurricane Agnes in 1972, but much of the deposit is probably attributable to the more severe periglacial conditions of the Pleistocene. Quartzite fragments of the Hardyston Formation predominate even where the colluvium is adjacent to gneiss. This probably reflects easier granular disintegration of the gneiss. which is often weathered to appreciable depth, rather than derivation predominantly from the less extensive Hardyston terrane.

The lower limit of colluvium is mapped at the margin of soils considered to be of quartzite and gneiss derivation on the Berks County soils map (Ackerman, 1970), though scattered quartzite pebbles are found well beyond these limits. The upper limit against the margin of the hills is more tenuous as it often involves distinction between residual and transported material of the same composition above the parent rock. It is based primarily on topographic and textural features observable on aerial photographs. Colluvium shown within the hill area is limited to areas where Hardyston debris is known to spread over the gneiss and grade up into talus.

The deposit extending across the Oley Valley flat is probably a terrace deposit of local derivation, but the soil is indistinguishable from colluvial deposits.

Much of the colluvium is probably only 3 to 4 m (10 to 13 ft) thick, as demonstrated by windows through it at various places and the amount of material excavated in the gravel pit 1 km (0.7 mi) east of Berkley. Apparently colluvial material in excess of 30 m (100 ft) thick is penetrated by wells in the valley between Dear Path Hill and Bernharts Hill. Similar thicknesses may exist elsewhere at some points close to the hills. A well southwest of Lyons is reported to have penetrated nearly 60 m (200 ft) of unconsolidated material, but much of it appears to be older residuum beneath the colluvial gravel.

Alluvium

Alluvial deposits of modern streams are mapped according to the distribution of alluvial soils shown by the Berks County soil survey (Ackerman, 1970). The coarseness and character of these deposits depends substantially on the local gradient of the stream and the type of bedrock being traversed. Deposits along the Schuylkill River show evidence of long-distance sedimentary transport, notably by an abundance of anthracite silt, particularly in upper layers deposited since the commencement of mining in the upper Schuylkill drainage area. Megascopically identifiable clasts in alluvial deposits of local streams generally reflect subjacent or nearby lithologies, though streams traversing the colluvium may carry Hardyston Formation clasts well beyond the limits of the colluvium.

Man-Made Deposits

Numerous accumulations of various materials deposited as the result of human activities are found throughout the area. Generally these are not regarded as geologic materials, but certain deposits that are sufficiently extensive to obscure significant tracts of the underlying rock and may have some potential economic value have been indicated on Plate 1.

A slag pile northeast of Temple has been delineated on the map. The desilting basins are diked basins used for impounding redeposited alluvium dredged from the Schuylkill River during river improvement projects; the deposits are largely winnowed of material finer than coarse sand size. One of the desilting basins is currently worked for gravel and may represent a potential source of anthracite silt or "river coal."

STRUCTURE

The structure of this area has long been recognized as extremely complex. Lesley and others (1883) first specifically compared the Lehigh Valley geology to that of the Alps. That view received little support for many decades as the nature of alpine geology was explicated, but it does accord well with the present interpretation of tectonic evolution in the Lower Paleozoic. The classical Appalachian view, presented by Miller and others (1941) for Lehigh County, essentially regards the traverse from the Reading Prong to the Upper Paleozoic rocks of the Valley and Ridge fold system as being the crest and limb of a great anticline, complex in detail, but generally simple in plan. This view is reflected by Buckwalter (1962) but is disputed by Stose and Jonas (1935) who concluded, partly on defective evidence (Miller and Fraser, 1935; Fraser, 1938; Miller, 1944), that much of the western Reading Prong was composed of a great thrust sheet transported above carbonate rocks of the Lehigh Valley. The present work suggests modification of Stose and Jonas' interpretation, but its essential correctness is fundamental to understanding the structure of the area. Recognition of recumbent nappes in the carbonate rocks west (Gray, 1959) and east (Drake and others, 1966) of this area, which are now known to be characteristic of the Great Valley from the neighborhood of the Susquehanna River to New Jersey, and recognition of the allochthonous character of much of the adjacent shaly rocks (Stose, 1946), which are both developments of the pre-Silurian Taconic orogeny, confirm the accuracy of the description of Lesley and others. The subsequent development of these concepts, and their relationship to the Reading area generally, are summarized by MacLachlan and others (1975).

MAJOR STRUCTURES AND STRUCTURAL LEVELS

To clarify the relationship between the complex of structural units in this area, the tectonic map (Plate 2) shows division of the area into structural levels. These levels are symbolically designated by the deformation deemed principally responsible for their development, and alphabetically in order of superposition. Retention of the stratigraphic symbol Oh for the Hamburg sequence is appropriate as emplacement is a "zero" event prior to the deformations producing cleavages. D1 identifies the levels whose genesis is primarily attributable to development of the Taconic Irish Mountain nappe, though some later movement is likely. D2 applies to the upper slices which, though evidently derived from the nappe system, are much displaced, with respect to the D1 levels, on Alleghanian thrusts.

Hamburg Klippe (Oh1-7)

Stose's (1946) concept of a simple klippe comprising all allochthonous rocks in the shale belt on the northern side of the Great Valley is an oversimplification. The seven lithotectonic units recognized as gravitationally and tectonically superimposed in the Hamburg sequence, as well as other features on a regional scale (Root and MacLachlan, 1978), show a more complex evolution. The total assemblage of allochthonous rocks having a definable base northeast of the area (Alterman, 1971), however, constitutes a gross unit that can be encompassed by Stose's term, "Hamburg klippe." The term is less useful to the west where allochthonous rocks merge with wildflysch and slide deposits that are intimately commingled with autochthonous Martinsburg Formation.

The Hamburg rocks of this area, as shown in structure section A-A′ (Plates 1 and 2), are inferred to lie in the envelope of the nappe system close to the brow of the Irish Mountain nappe. Underthrusting of the nappe rocks along the Leinbachs thrust is certainly in part the result of the Alleghanian movement, which deflected the carbonate of the nappes around the end of the Reading Prong, but it may also have occurred during advance of the nappe. The underthrust relationship gives a less orderly superposition of the major units in the northwest corner than prevails elsewhere in the area.

The "Taconic" thrust of Stose (1946), which defines the base of the Hamburg klippe and is recognized as a real feature by Alterman (1971), is not exposed in the mapped area. A possible position is suggested at the northwest end of section A-A′ (Plate 1).

Irish Mountain Nappe (D1a-d)

The Irish Mountain nappe exposed north and west of the Reading Prong is partially divided into two structural levels by a thrust that is interpreted to arise from general flow in the axial zone of the Irish Mountain nappe. Larger scale development of the same kind of structure is conceived as possibly generating the higher Taconic levels underlying the southeastern part of the mapped area. They might properly be referred to a distinct, though related, nappe; but such distinction should be made on more data showing relationships east of the area.

Evansville Thrust

Exposures of the Jacksonburg and Martinsburg Formations near Evansville lie at a lower structural level than the Great Valley carbonates of the rest of the mapped area. The Evansville thrust separating these levels is cut off by the Leinbachs thrust, and it is evidently a purely Taconic feature. The approximate kilometer (0.6 mi) of displacement on section A-A′ (Plate 1) is consistent with that required to produce the relationships shown in the Evansville area, as augmented by drilling data from the Allentown Portland Cement Company (Gray, 1950). Eastward increase in the displacement is deduced from larger displacement of a thrust emerging from below the Leinbachs thrust at the same level in western Lehigh County, which is interpreted to be the same surface. Following this trend, displacement is inferred to be much diminished in the southern cross section (A-A′).

Several thrusts within the upper plate of this thrust (D1b) are interpreted as splays from the Evansville thrust. The most southerly bring up the Hardyston Formation and gneiss of the Irish Mountain nappe (section A-A′), which leads to the concept of the thrust evolving out of the axial zone of the nappe. It would thus lose definition down dip and the levels above (D1b) and below (D1a) would merge as suggested in the sections.

North Oley Plate (D1d)

Because the gneiss plate beneath the Oley Valley rises to 186 m (610 ft) below the surface at Oley (Gault and Hamilton, 1953) and the carbonates are locally entirely cut out below the Sinking Spring thrust, there is obviously not room for a complete section from the surficial Beekmantown Group to the gneiss, and an intervening thrust is required. Its position below the Sinking Spring thrust apparently relates it to the Taconic nappe development. Gneiss at the eastern margin of Oley Valley apparently belongs to this level, though the gneiss was raised relative to the valley by later faulting (D3?).

Buried Crystalline Rocks (D1c)

Because relationships are concealed under the Reading Prong, an alternate construction of the southern cross section might seem at least equally as reasonable as the one presented. This would make the crystalline rocks beneath the Oley Valley a more massive crystalline core development of the D1a-b level analogous to the Irish Mountain block. The most probable projection of structures in the Reading quadrangle, however, suggests the presence of younger upper limb rocks at depth, and implies the corresponding depression of the axial surface of the Irish Mountain nappe. The crystalline rocks must therefore belong to a distinct, higher level (D1c) between the north Oley surface exposure and the D1a-b level of the nappe. The distribution of crystalline rocks can be reasonably deduced from aeromagnetic information, but the level at which they occur has no surface expression in the mapped area.

Alleghanian Thrust Plates (D2a-b)

Two major low-angle thrusts truncating Taconic structures in the Sinking Spring quadrangle (MacLachlan and others, 1975) extend into this mapped area. They were interpreted to be dynamically related to a second cleavage (S_2), some folds, and numerous reoriented older structures that have a grain parallel to the trend of Alleghanian folds in Silurian to Upper Paleozoic rocks to the north. These structures are believed to represent the main phase of Alleghanian deformation and are designated D2 in this area.

The lower, Sinking Spring thrust plate (D2a) occupies only a small surface area and has no true exposure in the mapped area. The folded structure shown on the cross sections is projected from the Reading 7½-minute quadrangle. Detailed analysis of exposures in the Sinking Spring quadrangle indicates that this is D1 folding strongly modified by a D2 impress. Lithologically they are related to the distinct Lebanon Valley nappe.

The massive quartzite and gneiss of the Grings Hill thrust plate (D2b) preserve few features that might lead to unravelling their extended structural history. The widespread inversion of gneiss over quartzite inferred in the cross sections is probably inherited from Taconic development. The imbrication and some folding relate to the Alleghanian emplacement of these rocks, which cut across several levels of the Taconic nappe system where the Grings Hill plate extends beyond the limits of the Sinking Spring plate.

AEROMAGNETIC INTERPRETATION

The only rocks in the mapped area producing significant local perturbations in the intensity of the earth's magnetic field are the gneisses of the Reading Prong. This property permits evaluation of the distribution and vertical extent of the gneiss by magnetic measurements. The aeromagnetic pattern of exposed gneiss in this area (Bromery and others, 1960), and in the Reading Prong generally (Bromery and Griscomb, 1967), is an extremely complex "birdseye maple" pattern, in part attributable to difficulty in keeping the aircraft at a constant elevation above the hilly terrane, but primarily the result of local variations in magnetite concentration in the gneiss. Variations in total iron content between granitic and more mafic (hornblende) gneisses appear to have no effect. Petrographic descriptions of the gneisses indicate that the magnetite content of the bulk gneiss is somewhat variable, ranging from less than one percent to about five percent; but the variation is apparently random, and occurs on a relatively small scale. Reports on the nineteenth-century iron mines show individual areas of higher magnetite concentrations to be small but widely distributed. These variations in magnetite content are evidently the essential feature causing the very complex, small-scale magnetic pattern.

Examination of the original magnetic maps (Bromery and others, 1960) shows that the small-scale roughness is superposed on larger scale variations in average magnetic intensity. These larger scale variations are believed to be almost entirely the effect of the thickness of surface and shallow gneiss bodies at various areas within the Reading Prong. A qualitative smoothing procedure was devised to evaluate these large-scale variations in this area and also in the Delaware River area. In the latter area Drake (personal communication) says the rigorous mathematical analysis of aeromagnetic anomalies from the same set of magnetic-survey data shows good agreement with the thicknesses of gneiss bodies he deduced from geologic data in that area (Drake, 1967). Thicknesses of gneiss bodies used in cross sections in the Temple-Fleetwood area are derived by calibration of the local larger scale anomalies by thickness-intensity ratios obtained in the Delaware River area. A map of smoothed aeromagnetic total-intensity variations of Precambrian rocks in the Reading 15-minute quadrangle and a description of data-reduction procedures is on open file at the Pennsylvania Geological Survey.

TIMES OF DEFORMATION AND THEIR CHARACTERISTICS

Precambrian

In areas of better exposure it is obvious that intense deformation accompanied metamorphism of the Precambrian rocks. Little is known of this deformation on a regional basis and nothing can be added from the poor exposure in this area (Buckwalter, 1962). Regionally, radiometric ages and structural relationships indicate Grenville and post-Grenville events, but these belong essentially to the tectonic pre-history of this area.

Classical Taconic

The author conceives the development of nappe structures involving all Middle Ordovician and older rocks of southeastern Pennsylvania as being intimately connected with the emplacement of slide deposits and slices of continental slope and deep-water, predominantly siliciclastic rocks over partly contemporaneous shelf carbonates (Root and MacLachlan, 1978). Emplacement of the allochthonous rocks, however, occurred in advance of the developing nappes and represents the principal Taconic feature recognized in the type Taconic area of New York and Vermont. Whereas the thrusts separating the higher lithotectonic units of the Hamburg sequence may be contemporaneous with the advance of the Irish Mountain nappe into this area, it appears that the Hamburg sequence was basically emplaced in the Martinsburg Formation terrane prior to local development of the nappe system. The Hamburg sequence and the Martinsburg Formation collectively form the pelitic envelope of the nappe system. This envelope appears to be a matrix that is common to the whole system rather than associated with any particular nappe.

Detailed structure of the Hamburg sequence is extremely complex and was only superficially examined in the preparation of this report. Some hint of the character of events associated with the classical Taconic emplacement of the Hamburg sequence is provided by published examples. Bergstrom and others (1972) infer slides of Lower Ordovician carbonate into lithotectonic unit 1 in the Hamburg quadrangle. Folding older than the cleavage is inferred in the Sinking Spring quadrangle (MacLachlan and others, 1975). A Taconic thrusting and associated wildflysch are described by Alterman (1971) as bounding the Hamburg sequence to the northeast. Pervasive cleavage associated with the nappe development and later structures obscure these early Taconic structures.

Taconic Nappes (D1)

The great recumbent folds that dominate the cross sections of this report, as well as their associated thrusts and minor structures, have no expression in the latest Ordovician and younger rocks that overlie them north of the mapped area. This is the oldest deformation that is known to affect the shelf carbonates of this area, and the associated cleavage (S1) appears to be geometrically identical to principal cleavage of argillaceous rocks to the northwest (MacLachlan and others, 1975). With due regard to the existence of several prior events noted above, this generally identifiable oldest deformation has been designated D1 here and in the Sinking Spring quadrangle.

Irish Mountain Nappe

The Irish Mountain nappe includes most of the carbonate rocks in the mapped area and is the major recumbent structure of the cross sections. It first appears to the west beneath the Lebanon Valley nappe in the Sinking Spring quadrangle (MacLachlan and others, 1975), takes its name from the fragment of its crystalline core forming Irish Mountain in the Temple quadrangle, and has presently uncertain eastward extent. It may be the same as the South Mountain nappe of Drake (1973) in the Allentown area. The choice of the name "South Mountain" is unfortunate, because that feature is among the most obscure of the several structurally important "South Mountains" of Pennsylvania. The same name would have been the obvious choice for the Grings Hill thrust from the "South Mountain" near Wernersville, but the name was avoided for this reason. The "South Mountain" nappe extends to the vicinity of Hellertown, where the underlying Musconetcong nappe emerges.

The Irish Mountain nappe comprises several slices in this area (levels D1a-d, Plate 2), which are believed to have developed from the axial zone of the nappe during the Taconic movement, though this model may be excessively simplistic. The upper crystalline slice underlying the Oley Valley is interpreted to be faulted up, and forms the hills east of the valley in the Manatawny and Boyertown quadrangles. This slice may be sufficiently extensive eastward to warrant recognition as a distinct nappe, though it is evidently of the same general provenance and genesis as the Irish Mountain nappe.

The Lehigh Valley sequence of Cambro-Ordovician sediments (MacLachlan, 1967; MacLachlan and others, 1975) is structurally associated with the Irish Mountain nappe and eastward continuations of the nappe system.

Leinbachs Thrust

Thrusting of the Lehigh Valley sequence under, or into, the Hamburg sequence along the Leinbachs thrust may well have been initiated during the Taconic nappe movement. The small klippe west of Rickenbach that lies east of the tear-fault segment of the Leinbachs thrust particularly suggests this relationship. There seems no doubt, however, that substantial movement at this locus is associated with later Alleghanian thrusting.

Lebanon Valley Nappe

Regionally inverted Cambrian and Ordovician rocks of the Lebanon Valley sequence occupy the Lebanon Valley from the vicinity of Wernersville westward (MacLachlan and others, 1975). These rocks represent exposures of the lower limb of a great recumbent structure of apparent Taconic age which has been designated the Lebanon Valley nappe. Stratigraphic similarities suggest that rocks of the northern Piedmont in Lancaster County belong to the same sequence and, presumably, the same structural system. Rocks having affinity to the Lebanon Valley sequence are unknown elsewhere, except for what is interpreted to be a younger Alleghanian thrust slice extending from the eastern Lebanon Valley into the southern part of the mapped area (level D2a, Plate 2), having been derived from the upper limb of the Lebanon Valley nappe. In the Reading quadrangle, the nappe contains formations older than any exposed in the Lebanon Valley, which are known elsewhere only in the northern Piedmont.

Lyons Station-Paulins Kill Nappe

Bromery and Griscomb (1967) propose the existence of a buried block of crystalline rock extending from Lyons Station, at the eastern edge of the mapped area, northeastward into New Jersey. Drake (1969, 1973) identifies this with a buried structure he names the Lyons Station-Paulins Kill nappe. The western end of this structure should lie approximately below the antiformal flexure of the Irish Mountain nappe in the eastern structure section (section C-C′, Plate 1). Sufficient speculative interpretation has been exercised in projecting surface structures to the depth shown without attempting to include this feature. It serves to illustrate, however, the complex nature of the nappe pile that is believed to fill the space between the floating crystalline rocks of the Reading Prong and true basement,which probably lies more than 5 km (16,000 ft) lower in this area.

Alleghanian, Main Phase (D2)

Several water wells located near the margins have passed through the Sinking Spring and Grings Hill thrust plates, confirming the low dip of the underlying thrusts. It is evident from the map of this area that these thrusts truncate older structures, and detailed studies in the Sinking Spring quadrangle (MacLachlan and others, 1975) have shown they are related to the Upper Paleozoic Alleghanian deformation. Folding of the same age may be represented by minor structures, which have not been clearly separated from older ones in this area, but the warping of the older nappes on a large scale seems definitely attributable to this event.

A second cleavage (S_2) is prevalent only in the structurally sensitive argillaceous rocks of the Martinsburg Formation and Hamburg sequence. Incipient development of this surface in carbonate rocks of the Sinking Spring thrust plate is common to the south and southwest, and presumably affects the ill-exposed rocks of this level (D2a) in the Temple-Fleetwood area. S_2 development is not known in massive carbonates underlying the Alleghanian thrust sheets, though it may occur in the Jacksonburg Formation. The exposed lithologies of the Grings Hill thrust plate (D2b) are unsuitable for cleavage development. The Paleozoic structural history of these rocks appears to be closely parallel to that of the Sinking Spring plate, but they preserve little impress of these events beyond the gross structure.

A notable feature of this area, which becomes even more prominent when examined in regional context on the state geologic map (Gray and others, 1960), is the southward deflection of the Great Valley around the western end of the Reading Prong. With the exception of Irish Mountain, the rocks of the Reading Prong exposed in this area lie in the upper Alleghanian thrust plate. It is proposed that it is precisely the movement system emplacing this plate, but also acting at deeper levels, possibly on reactivated D1 thrust surfaces, that produces the deflection of the Great Valley trend. Thrusting of the carbonates beneath the Hamburg sequence along the Leinbachs thrust certainly occurred at this time, though there may be an older history of such movements. The tear segment of the Leinbachs thrust is certainly an aspect of these D2 movements, as are some similarly oriented steep faults having subhorizontal movement that were observed in the section of the Maiden Creek Member near Rickenbach.

Sinking Spring Thrust

The Sinking Spring thrust can be traced continuously from easternmost Lebanon County to its disappearance below the Reading Prong near Frush Valley. It brings rocks of the Lebanon Valley sequence, believed to be derived from the upper limb of the Lebanon Valley nappe, over the lower limb of the Lebanon Valley nappe in Western Berks County and over the Irish Mountain nappe in the report area. The Hyde Park shale belt is a slice entrained in the thrust which is believed to be scraped off the Irish Mountain nappe as exposed in the Wyomissing syncline of the Reading quadrangle.

Rocks of the southern Oley Valley, extending locally into the southeast corner of the mapped area, have Lebanon Valley stratigraphy, as marked notably by the presence of the Annville limestone. The structurally simplest solution places these rocks in the same slice as the Lebanon Valley rocks to the west and indicates continuity of the Sinking Spring plate under the southwestern end of the Reading Prong.

Grings Hill Thrust

The relatively thin plate of Hardyston Formation and gneisses identical to those of the western Reading Prong, which overlies the Sinking Spring thrust plate and forms South Mountain and Grings Hill in western Berks and eastern Lebanon Counties, is emplaced on a thrust of apparently the same origin as the Sinking Spring thrust. This has been designated the Grings Hill thrust (MacLachlan and others, 1975).

South Mountain and Grings Hill are evidently isolated outliers of the Reading Prong, and it seems appropriate to extend the name Grings Hill thrust to the thrust underlying parts of the Reading Prong in the same structural position. This includes all exposed Reading Prong rocks in the mapped area except at Irish Mountain, but the Grings Hill plate probably does not extend eastward of the Manatawny quadrangle. With the exception of the tract extending about 25 km (16 mi) northeast of Reading, rocks of the Reading Prong apparently more directly represent exposures of the crystalline cores of various Taconic nappes.

Reading Overthrust of Stose and Jonas

Stose and Jonas (1935) proposed that much of the western Reading Prong was a remnant of a great ''Appalachian'' (Alleghanian) thrust sheet which they designated the Reading overthrust. The present interpretation finds much conceptual merit in this proposal for the extreme western part of the Prong lying in and near the mapped area. The Reading overthrust was claimed to be more extensive, but it is a real feature equivalent to the upper plate of the Grings Hill thrust in this area.

The present interpretation agrees with Stose and Jonas' inclusion of the rocks of South Mountain in western Berks County, and the block between the Oley Valley and the Great Valley excluding Irish Mountain, in the thrust plate. Most of Stose's autochthon east of Irish Mountain, however, is included in the Grings Hill plate. Indeed, it is the obvious aeromagnetically thin character of this sector that makes easily explicable the repeated belts of overturned Hardyston Formation that Buckwalter (1962) found so perplexing when he attempted to explain them in terms of structures that could be related to a rooted basement anticline. With the inclusion of these rocks, the thrust probably extends much as shown by Stose and Jonas to the vicinity of Longswamp, where ''autochthonous'' rocks appear as shown on the north margin of the Prong. However, it is probable that rocks east of the Oley Valley, southeast of Pine Creek, and from Gap Hill, south of Longswamp, eastward, were emplaced as Taconic nappe elements.

The fact that the thrust plate is less extensive and, on the average, somewhat thicker, as inferred from aeromagnetic data, than depicted by Stose and Jonas negates the various specific objections made by Miller and Fraser (Miller and Fraser, 1935; Fraser, 1938; Miller, 1944). Their well-taken points, however, illustrate the dangers of too free an extrapolation of a limited body of data.

Late Alleghanian (D3)

A third generation of cleavage (S_3), sporadically developed in the Hamburg sequence and locally in shaly layers in the carbonates of the Sinking Spring quadrangle, was inferred to be associated with late high-angle thrusting (MacLachlan and others, 1975). Three cleavages are also present in the Hamburg sequence of this area (Alterman, 1971) and presumably represent the same events. The youngest of these is the D3 deformation, which is considered to have a late Alleghanian age on the basis that it does not appear in Triassic sediments to the south, but is younger than structures attributed to the main phase of Alleghanian deformation.

Oley Furnace Fault

The Oley Furnace fault, taking its name from the nineteenth-century iron furnace just north of the Oley Valley, defines the northern margin of the Oley Valley. It is interpreted to upthrow carbonate rocks of the Irish Mountain nappe system against the Precambrian rocks of the Grings Hill thrust plate which overlies them to the north. It is essentially unexposed, but it appears to represent an example of the type of structure that was previously inferred to be the major component in D3 deformation. Comparable steep thrusts that formed late in the deformational sequence are a prominent feature near the Delaware River (Drake, 1967; Drake and others, 1967). Evidence placing them as definitely younger than main Alleghanian deformation is not present, but it seems likely that they represent the same D3 event.

Triassic-Jurassic Normal Faulting

Deposition of Upper Triassic to lowest Jurassic sediments occurred in a basin whose formation was apparently partly fault controlled. Faulting was not limited to the Triassic, however, as the youngest Lower Jurassic beds of the Jacksonwald syncline in the Reading quadrangle are cut off by such a fault. Faults in the mapped area that are comparable to those cutting Triassic rocks cannot be as securely dated, though they clearly cut the Alleghanian thrusts. It is reasonable to suppose that they represent the same Mesozoic events.

The Tuckerton, Blandon, and Fleetwood faults, major transverse features of the carbonate valley which cut into the Reading Prong, were apparently active at this time. The Fleetwood fault, at least, may have some earlier history, as the map pattern suggests that displacement of carbonates near the Grings Hill thrust may exceed displacement of the thrust surface. Large displacements across the Blandon fault might also reflect earlier movements, but displacement of the Grings Hill thrust above the present level of exposure in the wedge between the Blandon and Tuckerton faults is also large, though indefinite in this case.

The Oley fault, which defines the northwest edge of the Oley Valley; the Alsace fault, which follows a major aeromagnetic discontinuity in the Reading Prong; and the College Heights fault, which defines the eastern edge of Bernharts Hill, are other major faults believed to be Mesozoic in age. Except for the College Heights fault, which is named for a town located just to the south in the Reading quadrangle, the faults are all named for communities they traverse in the mapped area.

The majority of lesser high-angle faults mapped in the area, as well as smaller ones observed only in single exposures, probably belong to the same generation. The principal exceptions are the faults displacing quartzite ridges in the Grings Hill plate, which are probably Alleghanian tears associated with the imbrication of this plate.

JOINTS

A well-developed blocky joint pattern is generally characteristic of the rocks in the report area. Joint relationships have not been examined in detail in the poorly exposed crystalline rocks, but jointing is evident as a controlling factor that influences the shape of large float blocks. Incipient fracture may often be observed within the larger blocks, but planes of easy parting are often spaced as much as a meter (3 ft) apart.

In the sedimentary rocks, the majority of joints are nearly perpendicular to, or steeply inclined to, bedding, though less abundant joints having diverse orientations may be observed in almost any substantial exposure. Joint spacing is usually a function of bed thickness and lithology. It may often be more than 60 cm (2 ft) in massive quartzite and sandstone and is commonly on the order of 10 cm (4 in.) or less in shales and argillaceous limestone. Intermediate values are usually characteristic of the typically thick-bedded limestones and dolomites, though individual brittle dolomite beds between relatively more plastic limestones are sometimes intensely fractured.

In typical exposures there are usually two or three predominant joint sets having fairly regular spacing, though the characteristic spacing may be different for each set, and the most prominently developed set may be different in different exposures. Joint sets approximately perpendicular to the bedding strike and sets approximately perpendicular to bedding and parallel to bedding strike are usually most prominent; sometimes a set having intermediate orientation is more conspicuous.

The relationship between bedding and jointing is well shown in Figure 3a. In this diagram all beds have been restored to horizontal by rotation around bedding strike. Strike of bedding in each case has been brought to a uniform east-west direction so that the data from diversely oriented beds may be directly compared. As less common orientations can be observed in their proper ratio to the dominant joint sets only by collecting a large number of measurements at each exposure, the most prevalent orientations are proportionately underrepresented in this diagram. The strong tendency for joints to be perpendicular or steeply inclined to bedding is marked by the pronounced concentration toward the margin of the stereogram; the distinct maxima show preferred orientations that have logical relations to the fold structure. The principal maxima labeled ac and bc correspond to the sets qualitatively described above as perpendicular to and parallel to the bedding strike respectively, which were recognized to dominate most exposures. This designation indicates that these joints are formed parallel to ac and bc fabric planes of the fold system, and this relationship implies a common genesis. The slight asymmetry of the joint maxima with respect to the strike rotation axis is an effect of not correcting the initial rotation for the plunge of folds—a more elaborate correction for which data were not available in some cases. The subordinate maxima labeled S might possibly represent ac and bc fractures of an inclined second deformation, but it seems more probable that they are shears associated with the same stresses that developed the other joints. In either case, the joint pattern examined with respect to bedding is systematic, though relatively complex, and has four definable joint sets.

Whereas the orientation of joints in carbonate rocks is largely systematic with respect to the bedding, the present map distribution of joint orientations appears to be nearly random owing to diverse bed attitudes in this folded terrane. In an area such as that east of the Fleetwood fault (Figures 3c and 4c), where dips are generally moderate and the strike fairly uniform, there is sufficient coherence to the data so that one might attempt some broad generalizations of present joint orientations, but there is too much scatter to justify the hope that such generalizations would have any practical site-specific utility. Where the folding is more complex the joint orientation may be effectively random, even in a relatively small area (Figures 3b and 4d).

There appears to be a large component of truly random joint orientation in the shaly rock (Figure 3d). Bedding in these rocks is often obscure so that relations to bedding are indefinite. About half the joints determined at several stations near the Schuylkill River are approximately perpendicular to the principal shale foliation, which is largely cleavage generated, and there is some tendency for clustering of observations. This reflects the existence of systematic joint sets that do seem clearly related to the major deformational pattern; but a rotated construction, such as was used to rationalize the joint orientations in the carbonate rocks (Figure 4a), does not produce a comparably ordered pattern of jointing in the shales and is not reproduced here.

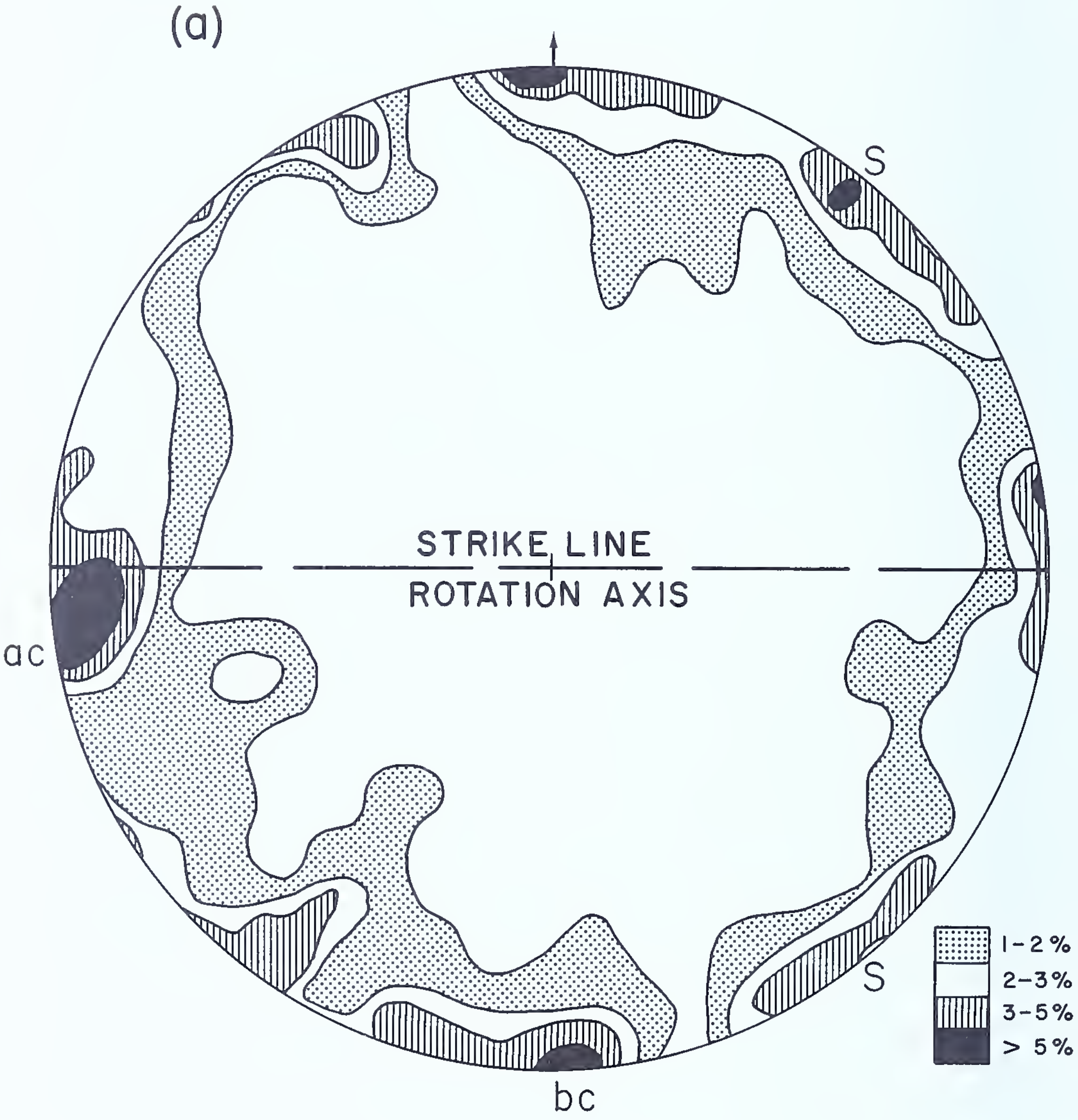

Figure 3. Joint orientations in the report area.

a. Two hundred forty-five joint poles from carbonate rocks; the position of the joints relative to bedding, rotated to horizontal about bedding-strike contours, shows the strong predominance of joints having steep inclination to bedding and four maxima geometrically related to the fold structure. About one sixth of all observations are scattered through the low-density central part of the diagram and represent joints having orientations apparently random with respect to bedding.

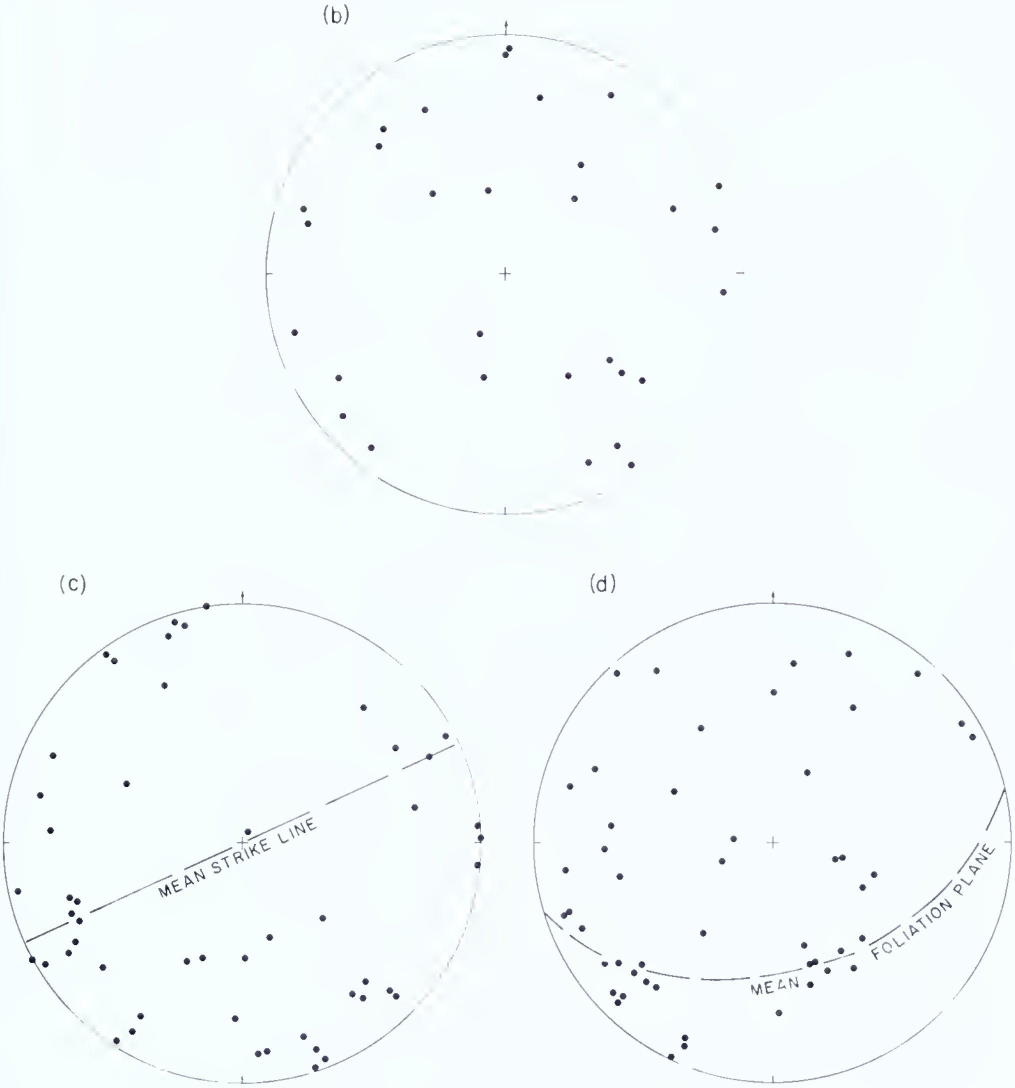

Figure 3. (Continued)

b. Thirty joint poles, present orientations, from a folded area south of Lake Ontelaunee. Orientation is apparently random with respect to geographic coordinates (about 1 square mile, or 2.6 km^2).

c. Fifty-one joint poles from carbonate rocks east of the Fleetwood fault. Data show considerable scatter of present orientations, though there is some evidence of a systematic relationship to the mean bedding strike of this fairly uniform area (about 10 square miles, or 26 km^2).

d. Forty-nine joint poles from shale along the Schuylkill River; present orientations. Data indicate that about half of the observations have a strong tendency to be perpendicular to the principal foliation surface (hence they lie near the trace of the mean foliation plane); the other half show essentially random distribution. Unlike in the carbonate rocks, joint-orientation statistics are not improved by rotation.

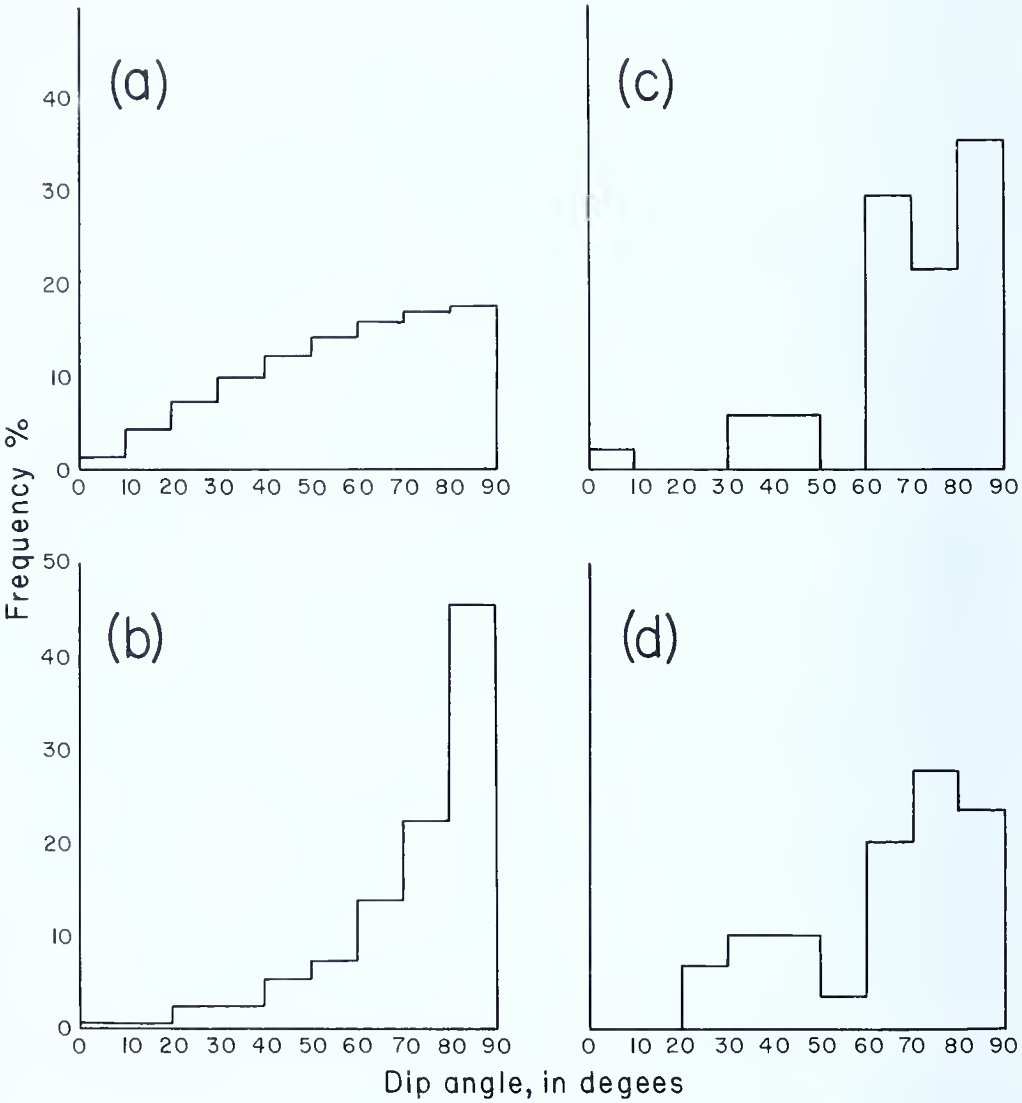

Figure 4. Joint dip frequencies in the report area.

a. Theoretical dip frequencies expected in a large sample drawn from a truly randomly oriented array of joints.

b. Inclination of joints with respect to bedding as shown in Figure 3a. There is a strong preferred orientation and a large angle between joints and bedding.

c. Fifty-one joints in carbonate rocks east of the Fleetwood fault, as in Figure 3c. There is a strong tendency for moderately steep to steep dips in this large area of fairly uniform bed orientation.

d. Thirty joints in folded carbonate rocks south of Lake Ontelaunee, as in Figure 3b. The small sample may show some tendency to steep dips as in (c), but the dip frequency distribution is not clearly significantly different from the random distribution in (a).

ENVIRONMENTAL AND ENGINEERING GEOLOGY

The soil and rock materials at and near the earth's surface are an important physical basis for the human environment. Understanding the nature, distribution, and properties of these materials is essential to economic use and minimum detrimental environmental impact.

Unconsolidated surficial material in this area has been mapped in detail by Ackerman (1970), who considers its use potential and engineering properties. Ackerman's soil map is an essential adjunct to this report for anyone concerned with the full range of site-specific properties. In the areas shown on the geologic map (Plate 1) to be covered by a veneer of unconsolidated sedimentary rocks, the soil map may give an unreliable indication of the bedrock character.

The geologic map (Plate 1) provides information on distribution of rock types and geologic structure for water well location and preliminary site selection projects, as well as a basis for estimating the mineral-resource potential of various areas. No major construction should be undertaken, however, without a site-specific geologic evaluation. The geologic map should expedite such evaluations, but it cannot show all of the relevant features at every location of possible interest.

For most practical uses in development or engineering, however, the variations in relatively subtle characteristics that provide the basis for discrimination among many of the numerous units of the geologic map may be of little consequence. On the other hand, surficial characteristics such as slope or flood risk, which are only indirectly reflected on the geologic map, may be very important. The map showing environmental geology factors (Plate 2) has been designed to emphasize the major environmentally distinct areas that may generally have different levels of suitability for different uses. The general characteristics of these areas are given in the map legend. It is hoped that this presentation will be particularly useful for land use planning and for directing development capital in suitable areas.

GEOLOGIC HAZARDS

Major geologic hazards, other than flooding in parts of this area, are limited to areas underlain by carbonate rocks and are directly attributable to the soluble character of these rocks. Solution openings in the bedrock, both as enlarged fractures and true caves, are only moderately well developed in this area and present no known hazard of major rock collapse, though they may be troublesome in quarrying and in establishing sound foundations for major structures. Known caves in the area are listed in Table 2. It should be noted that they occur over a wide stratigraphic range and are not limited to the major carbonate terrane of Plate 2. They also occur, perhaps relatively more abundantly, in the more restricted carbonate zones of the Hamburg

Table 2. *Known Caves in the Temple and Fleetwood Quadrangles*

(list from Turner and others, 1960)

Location		Cave name	Open passage length (feet)	Cavernous formation
40° N Lat.	75° W Long.			
28′ 40″	59′ 58″	Centerport (Mohrsville)	85	Hamburg sequence, lithotectonic unit 2
29′ 15″	54′ 35″	Dietrich	110	Hamburg sequence, lithotectonic unit 4
28′ 00″	53′ 54″	Evansville	80	Jacksonburg Formation
29′ 51″	51′ 08″	Merkel	500	Ontelaunee Formation
26′ 10″	59′ 45″	Noecker	130	Hamburg sequence, lithotectonic unit 2
28′ 00″	59′ 20″	Picnic Grove	20	Hamburg sequence, lithotectonic unit 2
23′ 55″	56′ 15″	Shearer	150	Allentown Formation, Muhlenberg Member
24′ 05″	55′ 50″	South Temple	1,000	Allentown Formation, Muhlenberg Member
24′ 36″	58′ 22″	Strondts Bridge (three caves)	140	Ontelaunee Formation
			70	
			15	
24′ 08″	56′ 36″	Tuckerton	40	Allentown Formation, Tuckerton Member

sequence (see Plate 1). Figure 5 illustrates the largest known cave in the area and represents a probable worst case example, though there may well be unknown caves of comparable magnitude. Drillers' records often show voids of considerable size.

Sinkhole development in soils above carbonate rocks is most prevalent where the water table is relatively deep, but sinkholes may occur almost anywhere. Many of the sinks appear to be old or recurrent features, but new development may occur, especially where the surface drainage pattern is modified or the water table is affected by heavy pumping. Sinkholes represent a significant danger of surface collapse which may damage structures. Major construction on carbonate rocks should be preceded by extensive investigation of local solution features and sinks, including extensive core drilling.

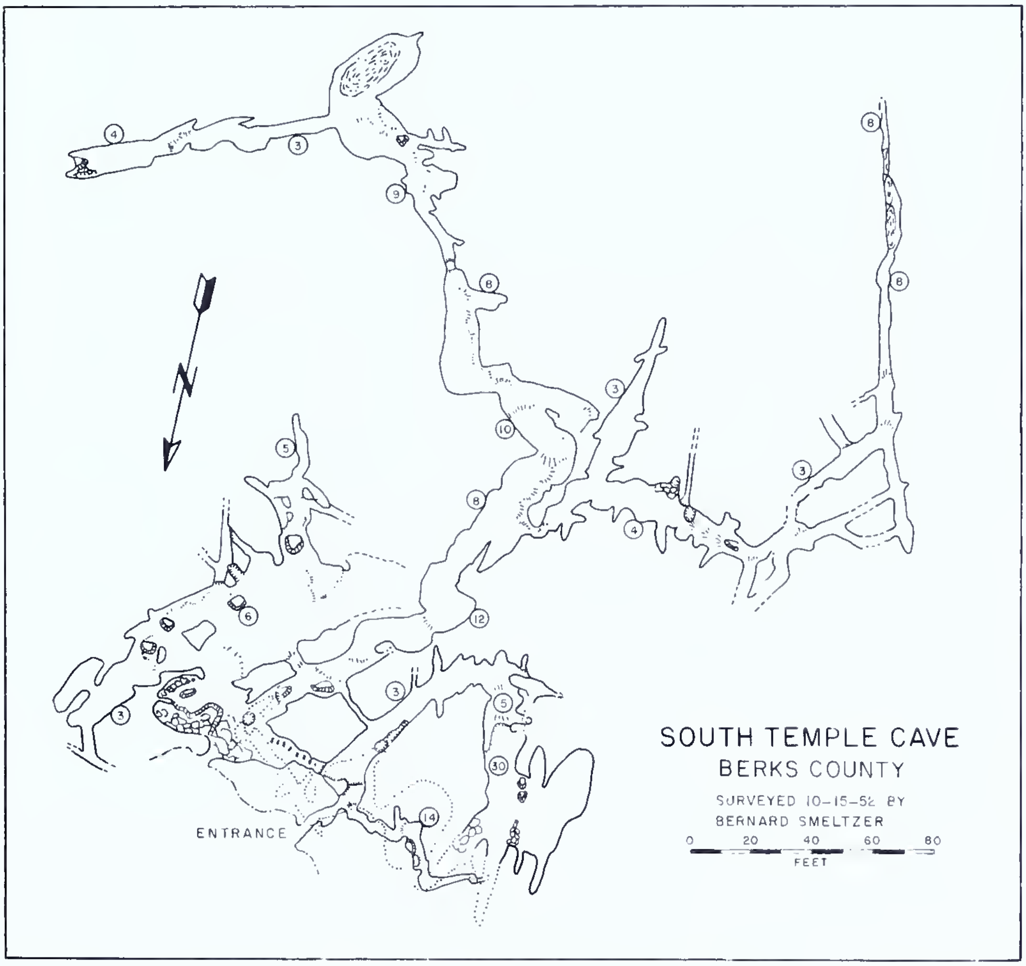

Figure 5. South Temple Cave, Temple quadrangle. This is the largest known cave in the mapped area and is indicative of the maximum development of major solution cavities likely to be encountered anywhere in the area. Data from Stone (1953, p. 66).

Rapid widespread pollution-dispersal events in groundwater may also arise from groundwater movement through connected solution openings. Possible pollution sources must therefore be sited and construction must be done with particular care on the carbonate rocks.

MINERAL RESOURCES

ALLUVIAL COAL

For a number of decades fine anthracite coal was recovered from the Schuylkill River alluvium by dredging in this area. Declining demand for the product and projects for improving the quality of the river caused discontinuance of these operations in the 1950's. As a result of increasing fuel prices, recovery of this material may well again become attractive, though environmental considerations indicate that the recovery procedures must be substantially modified from the former methods. Anthracite silt appears to be a significant component of deposits in the desilting basins, and it seems probable that processes for recovering this material while maintaining reasonable water flows and minimum disturbance of the river can be devised. This makes these basins especially interesting as a possible source of ''river coal,'' though the volume may be insufficient to support large operations.

BUILDING STONE

Little stone is used in contemporary construction and none of the flagging, ornamental facings, and similar materials currently used are native stone. Older buildings show extensive use of native stone from many sources. The condition of the stones in the oldest buildings indicates that most are eminently suitable. All units yielding substantial float boulders have been used as fieldstone or roughly dressed rock in numerous foundations and a number of attractive buildings. These range from conglomerate (lithotectonic unit 6) and graywacke sandstone (lithotectonic unit 1) in the Hamburg sequence through all the carbonate formations except the Jacksonburg and the upper part of the Leithsville, and include the Hardyston quartzite and Precambrian gneiss. Construction economics rather than availability are the limitation on their use.

Dressed quarry blocks of limestone were evidently produced at a number of the quarries in the area and were used in more formal construction. Some use of dressed granitic gneiss blocks has also been observed, though it is not clear that any were actually quarried in the mapped area. Known producers were located to the south at Reading and to the east at Seisholtzville. Flagstone from sandy beds in the Hamburg sequence (lithotectonic unit 1) is reported to have been produced east of Shoemakersville. Should a demand develop, suitable quarry locations exist in the area.

CRUSHED STONE

Crushed limestone is produced by Berks Products Corporation at South Temple. A full range of sizes is marketed, and the suitably sized grades are rated as class A coarse aggregate by the Pennsylvania Department of Transportation. The quarry fully occupies the available ground, and additional deepening is limited by support required by the adjacent highway and railroad. The reserves at this locality, especially favorably located for the Reading market area, are limited, but large reserves of comparable stone lie further out the valley. Much of the Allentown Formation and Beekmantown Group yield suitable quarry rock. A limiting factor in quarry development is the increasing cost of limestone land and widespread restrictive zoning due to the pressure of suburbanization.

Crushed quartzite from the Hardyston Formation is produced in conjunction with sand by the Berk Silica Sand Company. This material should have better skid-resistant properties for highway surfacing than the crushed limestone, which is poor, but for most uses the products are interchangeable. The Hardyston ridges provide many potential quarry sites for crushed stone.

CEMENT

Portland cement has long been produced from the Jacksonburg "cement rock" at Evansville. The area of stone of suitable quality is quite small. There does not appear to be any prospect for expansion of this industry, though the existing operation probably has sufficient reserves to sustain operations for some time.

CLAY AND SHALE

Brick is currently produced at Shoemakersville. The rock presently used is apparently all from lithotectonic unit 2 of the Hamburg sequence, though the quarry extends into unit 1. Beyond the mapped area, but nearby, unit 6 is used. Preliminary tests also indicate a potential for structural clay products in units 4 and 5, and in clays residual above carbonate rock of the valley. Results of firing tests for the Pennsylvania Geological Survey of some units appearing in this area have been reported in several publications, as shown in Table 3. Four recently obtained results are included in the appendix to this report.

Brick was once produced in the Oley Valley just south of the mapped area, but the volumes available from such residual occurrences compare poorly with the vast reserves of shale rock, which probably contain many suitable sites on land that is less valuable in alternative uses than the level and fertile limestone country.

Table 3. *Clay/Shale Test Samples of Pennsylvania Geological Survey in or Adjacent to the Temple and Fleetwood Quadrangles*

Unit sampled	Quadrangle	Reference
Allentown Formation, Maiden Creek Member(?)	Temple	O'Neill and others (1965), p. 87
Hamburg sequence, lithotectonic unit 1	Temple	O'Neill and others (1965), p. 83
Hamburg sequence, lithotectonic unit 2(?)	Hamburg	O'Neill and others (1965), p. 79
Hamburg sequence, lithotectonic unit 5	Bernville	O'Neill and others (1965), p. 77
Martinsburg Formation	Kutztown	O'Neill and others (1965), p. 81
Hamburg sequence, lithotectonic unit 1	Hamburg	Hoover and others (1971), p. 77
Hamburg sequence, lithotectonic unit 1	Hamburg	Hoover and others (1971), p. 79
Hamburg sequence, lithotectonic unit 1	Kutztown	Hoover and others (1971), p. 81
Martinsburg Formation	Topton	Hoover and others (1971), p. 227
Martinsburg Formation	Topton	Hoover and others (1971), p. 229
Hamburg sequence, lithotectonic unit 4	Bernville	This report, appendix, sample 177-B-1
Hamburg sequence, lithotectonic unit 6	Hamburg	This report, appendix, sample 186-C-1
Martinsburg Formation	Temple	This report, appendix, sample 187-A-1
Martinsburg Formation	Temple	This report, appendix, sample 187-A-2

The Martinsburg samples indicate some potential for lightweight-aggregate production. Ceramic clays are not known; but white clays marketed as filler were recovered in several operations in conjunction with mines in residual limonite on the carbonates. It is doubtful that economic recovery of these small patchy deposits could be achieved under modern conditions.

IRON AND IRON OXIDE PIGMENTS

Iron ores and pigments, the production of which was a significant factor in the local economy in the nineteenth century, are commodities of probably only historical interest. Deposits comparable to those mined still exist, but the economic factors that brought local production to a close around the turn of the century are more potent than ever. Technological changes have rendered some of the ores probably unmarketable even if produced.

Many dozens of small mines are known, and records of sales to local furnaces exist, but some of them could not be precisely located in the 1870's. Production was obtained from magnetite concentrations in the Precambrian gneiss and from limonitic "brown ore" in residual concentrations mostly upon the valley carbonates, but also upon the Hamburg sequence near Leesport. Descriptions of old workings are provided by D'Invilliers (1883).

Magnetite ore was produced both from surface cuts and underground workings. Deposits were lenticular; reports showed the only exception to be as much as 100 m (325 ft) of work along a single "vein." High silica content and refractory character of the ore, owing to the difficulty of separating siliceous gangue, made these ores usually less popular at the local furnaces, though modern magnetic-concentrating techniques would yield an excellent ore of low phosphorus and sulfur content. The deposits are probably too small to be economically worked, however.

Limonite ores were almost entirely produced by open-pit operations. Some efforts at underground mining in the deeper deposits encountered much difficulty from heaving and flow of plastic clays. Many workings were less than an acre in area, and ore usually did not extend below about 10 m (32 ft). The largest mine in the area was the Moselem mine in the north-central part, about 500 m (1,600 ft) southeast of St. Peters Church; the mine is about 520 m (1,700 ft) long and was worked to about 20 to 25 m (65 to 80 ft). At best, the brown ores of this region ran 50 percent iron and sometimes as low as 30 percent. They are often relatively high in phosphorus and are probably of no value for modern steel making.

Earthy ore, and highly ferruginous clays associated with the brown ores were used as mineral pigment. The area comprises part of the Lehigh valley district, which was nationally important in the paint industry. The pigment industry survived local iron mining by a number of years. The Williams Company plant, 2 km (1-1/4 mi) southeast of Fleetwood, one of the major producers in the state, was active in the 1930's (Wilson, 1933). Manufactured pigments have largely displaced mineral pigments, but it is conceivable that a market could be established for a local product if a large deposit of unusually uniform quality was found. The economics, however, remain questionable.

LIME

Agricultural lime was burned in stone kilns adjacent to numerous small quarries throughout the area at every stratigraphic level. Burned lime is not now much used and is provided by major producers in the Lebanon Valley district. Most agricultural liming is now done with dust and finely crushed stone produced as one product of general crushed limestone operations, and is supplied in part by Berks Products Corporation in South Temple. As much of the carbonate rock in the Great Valley and Oley Valley is suitable for crushed stone, it is reasonable to anticipate the development of new quarries from time to time which will yield entirely satisfactory agricultural stone.

Analyses reported by Gray (1951) show that some individual beds at various stratigraphic levels throughout the Beekmantown Group have sufficient purity to yield lime acceptable for plaster and other construction uses and some of the less demanding industrial requirements. There is indication that selective quarrying of some beds in several of the older quarries was used to supply the local building trades. This practice is not economically compatible with modern quarrying methods of low-unit-value materials of this kind. As a superior product is produced from the Annville Limestone in the region, the high cost of separating this relatively inferior stone is not justified. The quarry at Kirbyville in the Stonehenge Formation and several smaller quarries in the Epler Formation in Maiden Creek Township were worked primarily for blending in cement manufacture. High-calcium limestone from the Annville Formation is now trucked to Evansville from the southern Oley Valley. The cost of that operation is a fair reflection on the difficulty and expense of working the more favorable Beekmantown Group beds for even that relatively undemanding use.

METALLIC MINERAL POTENTIAL

The occurrence of major zinc deposits in the Rickenbach Formation in the Saucon Valley (Callahan, 1968) makes the Beekmantown Group of eastern Pennsylvania an area of continuing interest for zinc prospecting. The only known occurrence of zinc in the mapped area is some sphalerite collected in one or more of the quarries near the railroad between West Leesport and Rickenbach. A recent discovery of significant quantities of zinc in the Eastern Industries quarry in the Oley Valley and a very high (0.34 percent) zinc content in limonite at the Manweiler mine, which lies only 1.5 km (0.9 mi) south of the quadrangle line near Oley, suggests that an economic concentration of zinc may yet be found in this area.

Up to 15 percent zircon appears in association with magnetite at an abandoned iron mine about 2.5 km (1.6 mi) east of Pricetown and 0.6 km (0.4 mi) south of Seidel School (Gordon, 1922). Lesser amounts of zircon are reported in a number of magnetite ores in the area. It is doubtful that this occurrence represents an economic zircon deposit, but it does indicate the potential of zircon prospecting in the area.

Molybdenite found 1.4 km (0.85 mi) southwest of Pricetown is probably just a mineralogical curiosity, though additional occurrences in the Reading and Birdsboro quadrangles extending from the Hartman mine just south of the border of the mapped area to the Ohlinger Dam suggest that economic concentrations are not impossible.

SAND AND GRAVEL

Natural deposits of clean sand of commercial value are lacking in the area. Sand sufficient for local use is prepared by crushing the Hardyston Formation. Formerly, numerous operations, mostly of small size, obtained the material from shallow pits in selected locations where the Hardyston was deeply weathered and easily disaggregated. Additional localities of this type probably exist, but modern machinery makes it practical to crush fresh rock economically and produces coarser crushed aggregate as a co-product. The weathered Hardyston sand is quite pure and was used for ganister in steel manufacture as well as for masonry and concrete. Silica brick has also been manufactured from this material, though apparently not within the mapped area.

Gravel is, or has been, produced in limited quantities from the colluvium and from alluvium in the desilting basins. The terrace gravels also may have some potential. Most of the gravel-sized material used in this area, however, is locally produced, crushed limestone.

URANIUM

Though some uranium mineralization has been known in the Reading Prong for a long time, the area apparently has only recently become a target for serious prospecting. Gordon (1922) reports uranium-bearing allanite at the zircon locality east of Pricetown and, just outside the mapped area, more abundantly with autinite and some torbinite at the old Trexler mica mine. This appears to be the northern end of a uranium-bearing zone extending to McKnights Gap. McCauley (1961) describes uranium-bearing pegmatite near Pikesville east of the Oley Valley. Aerial gamma-ray surveys (LKB Resources, 1977) show significant radiation anomalies over the Reading Prong, and several major mineral producers are actively investigating the area (personal communications). The exact associations of radioactive minerals generating these anomalies are not known in most cases. Fossil placers in the basal conglomeratic Hardyston Formation rich in thorium, rare earths, and zirconium are known from the Allentown area (Smith, 1974), and could be prospected for those minerals here, but his association is unlikely to be uranium bearing. The uranium minerals reported by Gordon (1922) are associated with pegmatitic phases of the granitic gneiss. A similar association is reported (Smith, 1978) about 1 km (0.6 mile) east of Oley near the headwaters of Monocacy Creek. An overall uranium anomaly in this area, characterized by enrichment in linear shear(?) zones, appears to have genuine economic potential.

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GLOSSARY

Algal mat. A horizontally extensive layer of interlocking algal filiments or algal structures that may secrete calcium carbonate and serves as a trapping and binding medium for fine clastic particles, especially limestone, which may be solidified as an algal limestone.

Allochthon, allochthonous. A mass of rocks that has been moved from its original site of origin by tectonic forces composes an allochthon and comprises allochthonous rocks. The term may be restricted to rocks differing substantially in facies from contemporaneous *autochthonous* (q.v.) rocks. (See also *parautochthonous.*)

Argillite. The term is here used to describe rocks that contained a major proportion of clay minerals when they were deposited, and which might be recognized as shale, mudstone, slate, and phyllite.

Autochthon, autochthonous. A body of rocks that remains at its site of origin, in contrast to rocks that have been moved by tectonic forces. (See *allochthon* and *parautochthon.*)

Bioturbation. The churning and stirring of a sediment by organisms.

Calcarenite. A limestone consisting predominantly of detrital calcite particles of sand size. Sometimes applied loosely to the dolomitized equivalent.

Calcilutite. A limestone consisting predominantly of detrital calcite particles of silt and/or clay size.

Calcirudite. A consolidated calcareous gravel or rubble.

Carbonate terrane. The surface or area characterized by the outcrop of carbonate rocks.

Cataclasis. Rock deformation accomplished by fracture and rotation of mineral grains or aggregates without chemical reconstitution.

Clastic terrane. The surface or area characterized by the outcrop of clastic sedimentary rocks, here used with the implication of siliciclastic rocks as distinct from carbonate rocks.

Colluvium. Alluvium deposited by unconcentrated surface runoff and debris deposited by gravity movement, usually at the base of a slope.

Detrital carbonate. Carbonate rock composed of preexisting carbonate fragments mechanically deposited as a sediment.

Dolomicrite. A rock composed of microscopic (clay-sized) dolomite crystals.

Dolomitization. The process whereby limestone is converted to dolomite rock or dolomitic limestone by replacement of original calcium carbonate by calcium-magnesium carbonate (the mineral dolomite).

Graywacke. An impure sandstone containing rock fragments as well as quartz grains and generally having an abundant argillaceous to silty matrix. It is a common product of turbidity-current deposition.

Lithotectonic unit. A mappable unit of a tectonically assembled sequence which may be identified by a characteristic lithologic assemblage. The order of superposition of such units is independent of stratigraphic age.

Metasediment. A sediment or sedimentary rock that shows evidence of having been subjected to metamorphism.

Migmatite. A composite rock composed of igneous or igneous-looking and/or metamorphic materials, which are distinguishable in hand specimen.

Nappe. A large allochthonous (or parautochthonous), sheet-like tectonic unit that has moved along a predominantly subhorizontal surface.

Overthrust. A low-angle thrust fault of large scale.

Parautochthonous. Applied to rocks, or the nappes containing them, that are tectonically transported (allochthonous) but have lithologic facies that are generally similar to contemporaneous autochthonous rocks.

Pelletoidal. Descriptive of a carbonate rock containing accretionary micrite pellets, possibly of fecal origin.

Primary dolomite. A dolomite rock deposited as the mineral dolomite or dolomitized in the earliest rock-forming phase.

Ribbon limestone. A limestone having thin bands of contrasting colors produced by stratification; applied in this area to thin-bedded calcilutites that have interlayered shales.

Shale terrane. The surface or area characterized by the outcrop of shale and related rocks.

Sharpstone conglomerate. Sedimentary breccia produced by mechanical disruption of immediately underlying strata.

Shelf carbonate. Carbonate rock of intratidal to moderately shallow marine origin deposited in thick accumulations on a continental shelf or ocean-basin margin.

Siliciclastic. Clastic rocks composed predominantly of silica and/or silicate minerals.

Stromatolite. Variously shaped laminated structures of calcareous sediments formed under the influence of a mat of sediment-binding algae.

Supratidal. Pertaining to the shore area just above the high-tide level.

Tectonization. The process of producing a tectonic rock texture, which characterizes a tectonite.

Tectono-stratigraphic unit. A unit that is approximately equivalent to a lithotectonic unit but whose position in a tectonically superposed sequence is emphasized; it is not necessarily lithologically distinguishable from other units of the sequence.

Thrust slice. The body of rock overlying a thrust fault that has moved along the fault.

Wildflysch. A rock of flysch facies containing large, irregularly sorted blocks or boulders resulting from tectonic fragmentation, and contorted or jumbled beds resulting from slumping or sliding under the influence of gravity.

APPENDIX

FIRING-TEST RESULTS OF SHALE SAMPLES COLLECTED DURING PREPARATION OF THIS REPORT[1]

Sample Number 177–B–1

Location: Bernville 7-1/2-minute quadrangle, 40°24′04″N/76°00′06″W. Quarry west of township road about 1 mile (1.6 km) northwest of Leinbachs.
Geologic unit: Hamburg sequence, lithotectonic unit 6.
Lithology: Greenish-gray shale having somewhat blocky parting.
Sampled interval: Twenty-two feet (6.7 m) lying just west of a 6-ft (1.8-m) purple shale bed in the center of the quarry.

Raw properties:
Water of plasticity, percent: 18.3 Working properties: Short
Drying defects: None Drying shrinkage, percent: 2.5 Dry strength: Fair

Slow-firing test:

Temp. °F	Munsell color[2]	Moh's hardness	Percent total shk.	Percent abs.	Percent app. por.	Bulk dens. gm/cc
1800	5YR7/6 Moderate yellowish pink to moderate orange	3	2.5	18.1	33.5	1.85
1900	2.5YR5/8 Brownish orange	5	5.0	15.2	29.8	1.97
2000	2.5YR4/6 Strong brown	6	5.0	12.6	25.8	2.05
2100	2.5YR4/4 Moderate reddish brown	7	7.5	10.0	21.4	2.14
2200	2.5YR3/4 Moderate reddish brown	7	7.5	7.3	16.2	2.23
2300	7.5YR4/2 Grayish brown	8	10.0	2.0	4.7	2.35

Bloating test: Negative
Other tests: ph—6.7; no effervescence with HCl.
Potential use: Structural clay products (e.g., facing brick).
Remarks: Good firing range (1900-2200°F).

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[1] Based on preliminary data obtained from the Tuscaloosa Metallurgy Laboratory of the U.S. Bureau of Mines.

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[2] Munsell color names were taken from American Society of Testing and Materials (1975).

Sample Number 187-A-1

Location: Temple 7-1/2-minute quadrangle, 40°29′08″N/75°53′40″W. Abandoned railroad cut east of Ontelaunee Reservoir, 3/4 mile (1.2 km) north of Evansville.
Geologic unit: Bushkill Member(?), Martinsburg Formation.
Lithology: Dark-gray phyllitic shale having thin silt streaks.
Sampled interval: Eighteen feet (5.5 m).

Raw properties:
Water of plasticity, percent: 17.3 Working properties: Short
Drying defects: None Drying shrinkage, percent: 5.0 Dry strength: Fair

Slow-firing test:

Temp. °F	Munsell color	Moh's hardness	Percent total shk.	Percent abs.	Percent app. por.	Bulk dens. gm/cc
1800	2.5YR6/8 Moderate orange	3	5.0	13.9	27.0	1.95
1900	2.5YR4/6 Strong brown	7	7.5	5.4	12.1	2.16
2000	2.5YR3/4 Moderate reddish brown	7	7.5	2.2	4.7	2.24
2100	—	—	Melted	—	—	—

Bloating test: Positive.
Other tests: pH—7.7; slight effervescence with HCl.
Potential use: Not suitable for use in structural clay products. Marginal lightweight aggregate.
Remarks: Abrupt vitrification (1800-1900°F). May be limy.

Crushing characteristics: Platy
Particle size: 3/4″ pieces Retention time: 15 minutes

Temp. °F	Percent absorption	Bulk density gm/cc	Bulk density lb/ft^3	Remarks
1800	10.9	1.93	120.4	No expansion.
1900	9.1	1.65	103.0	Slight expansion.
2000	11.2	0.95	59.3	Good pore structure.
2100	—	—	—	—
2200	—	—	—	—
2300	—	—	—	—

Comments: Marginal for use as lightweight aggregate. Short firing range. May have to be pelletized.

Sample Number 187-A-2

Location: Temple 7-1/2-minute quadrangle, 40°29′03″N/75°53′41″W. Railroad cut east of Ontelaunee Reservoir, just south of tributary creek north of Evansville.
Geologic unit: Bushkill Member, Martinsburg Formation.
Lithology: Isoclinally folded, dark-gray slaty shale.
Sampled interval: Twenty-five feet (7.6 m) perpendicular to cleavage.

Raw properties:
Water of plasticity, percent: 18.0 Working properties: Short
Drying defects: None Drying shrinkage, percent: 2.5 Dry strength: Fair

Slow-firing test:

Temp. °F	Munsell color	Moh's hardness	Percent total shk.	Percent abs.	Percent app. por.	Bulk dens. gm/cc
1800	2.5YR6/8 Moderate orange	3	2.5	13.1	25.9	1.97
1900	2.5YR4/6 Strong brown	7	7.5	5.3	12.0	2.28
2000	2.5YR3/4 Moderate reddish brown	7	7.5	2.2	5.3	2.35
2100	—	—	Melted	—	—	—

Bloating test: Positive.
Other tests: pH—7.4; no effervescence with HCl.
Potential use: Not suitable for use in structural clay products. Marginal lightweight aggregate.
Remarks: Abrupt vitrification (1800-1900°F).

Crushing characteristics: Tabular
Particle size: 3/4″ pieces Retention time: 15 minutes

Temp. °F	Percent absorption	Bulk density gm/cc	Bulk density lb/ft³	Remarks
1800	6.4	2.20	137.3	No expansion.
1900	8.4	1.64	102.3	Slight expansion.
2000	8.2	1.59	99.2	Slight expansion.
2100	9.6	0.95	59.3	Some large pores; sticky.
2200	—	—	—	—
2300	—	—	—	—

Comments: Marginal for use as lightweight aggregate. Short firing range. May have to be pelletized.

Sample Number 186-C-1

Location: Hamburg 7-1/2-minute quadrangle, 40°30′10″N/75°53′29″W. Borrow pit on south side of Pa. Route 662 about 1/2 mile (0.8 km) west of Moselem.
Geologic unit: Hamburg sequence, lithotectonic unit 4.
Lithology: Greenish-gray micaceous silty shale.
Sampled interval: Twenty-five feet (7.6 m); chips at 1-foot (0.3-m) intervals at west end of pit.

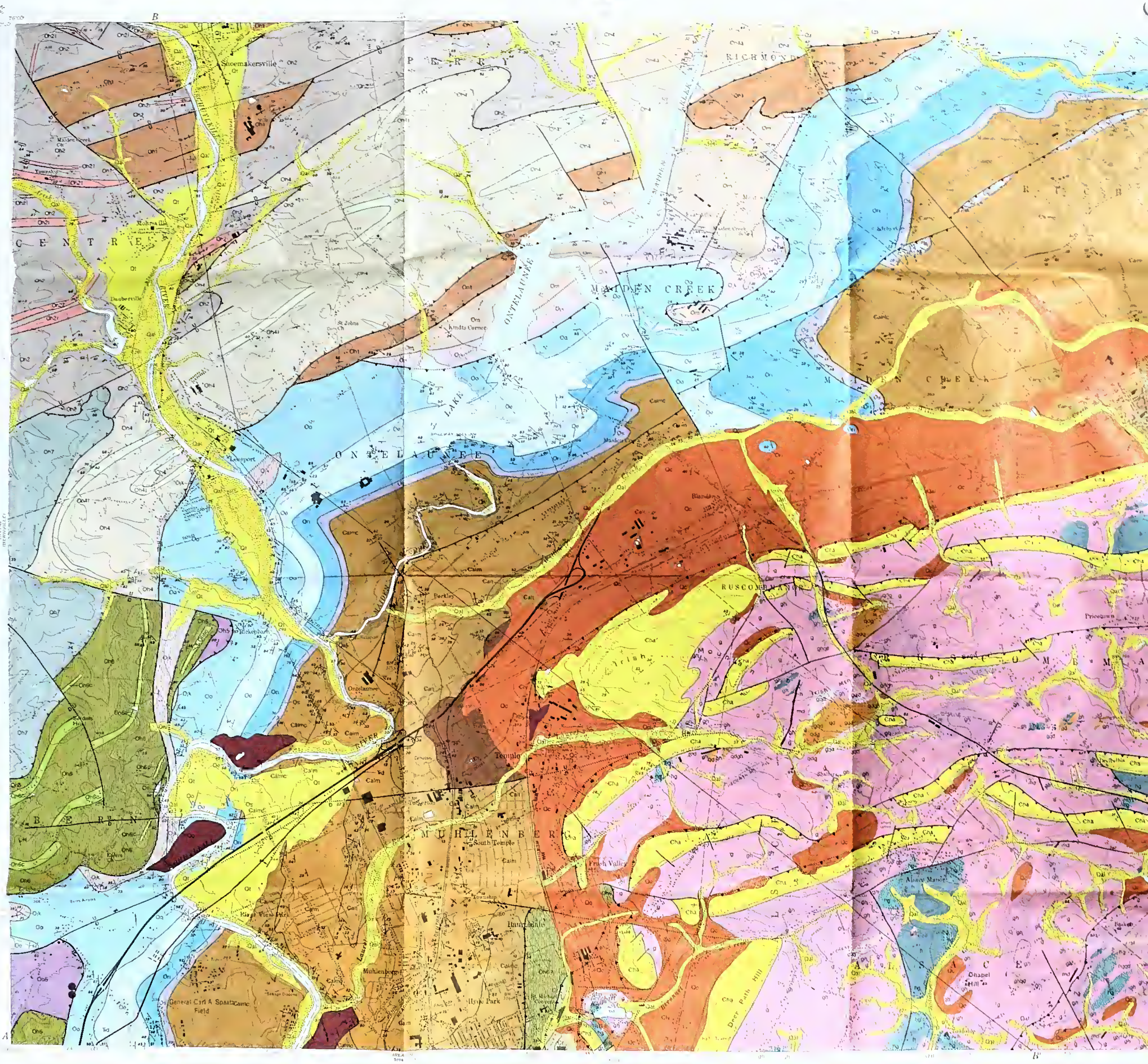
Raw properties:
Water of plasticity, percent: 17.2 Working properties: Short
Drying defects: None Drying shrinkage, percent: 2.5 Dry strength: Fair

Slow-firing test:

Temp. °F	Munsell color	Moh's hardness	Percent total shk.	Percent abs.	Percent app. por.	Bulk dens. gm/cc
1800	2.5YR6/8 Moderate orange	3	2.5	13.0	26.0	2.00
1900	2.5YR4/8 Strong brown	6	7.5	7.5	16.7	2.23
2000	2.5YR4/6 Strong brown	7	7.5	4.7	10.9	2.33
2100	2.5YR4/4 Moderate reddish brown	7	7.5	3.4	7.9	2.36
2200	2.5YR3/4 Moderate reddish brown	7	7.5	1.8	4.4	2.40
2300	—	—	Melted	—	—	—

Bloating test: Negative.
Other tests: pH—7.0; no effervescence with HCl.
Potential use: Structural clay products (e.g., facing brick).
Remarks: Good firing range (1900-2150°F).

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*



Base map from U.S. Geological Survey Temple and Fleetwood 7½-minute quadrangles.

Copyright 1979 by the Commonwealth of Pennsylvania

Base map from U. S. Geological Survey Temple and Fleetwood 7½-minute quadrangles.

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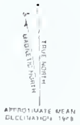


GEOLOGIC MAP OF THE TEMPLE AND FLEETWOOD QUADRANGLES, BERKS COUN

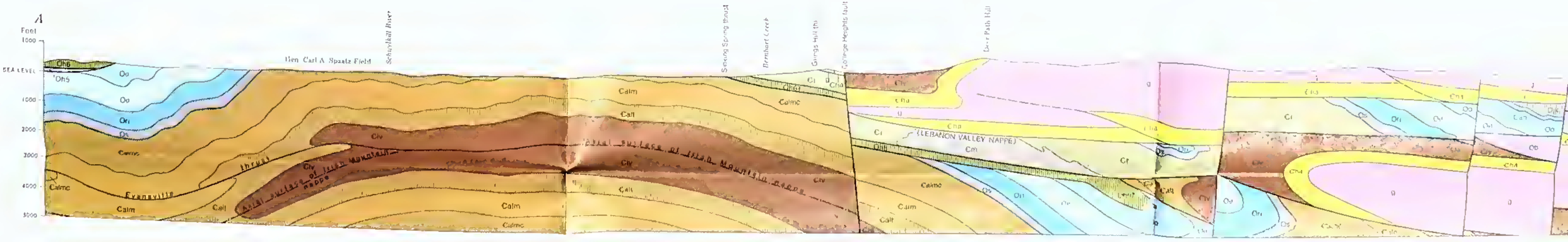
BY DAVID B. MACLACHLAN

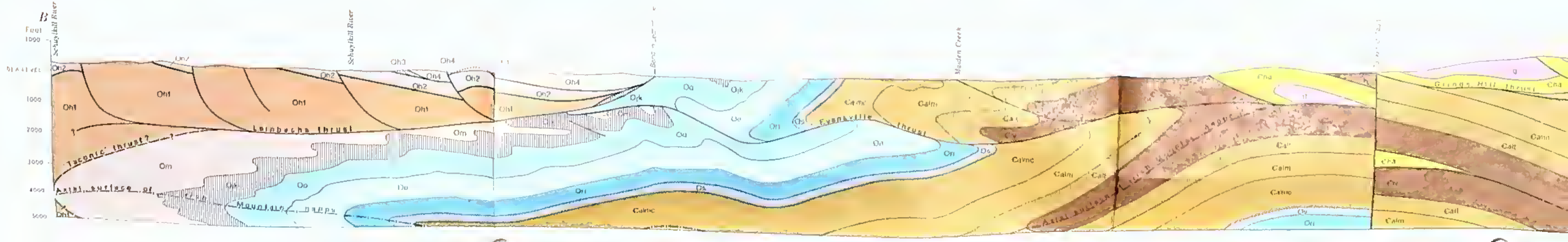
1979

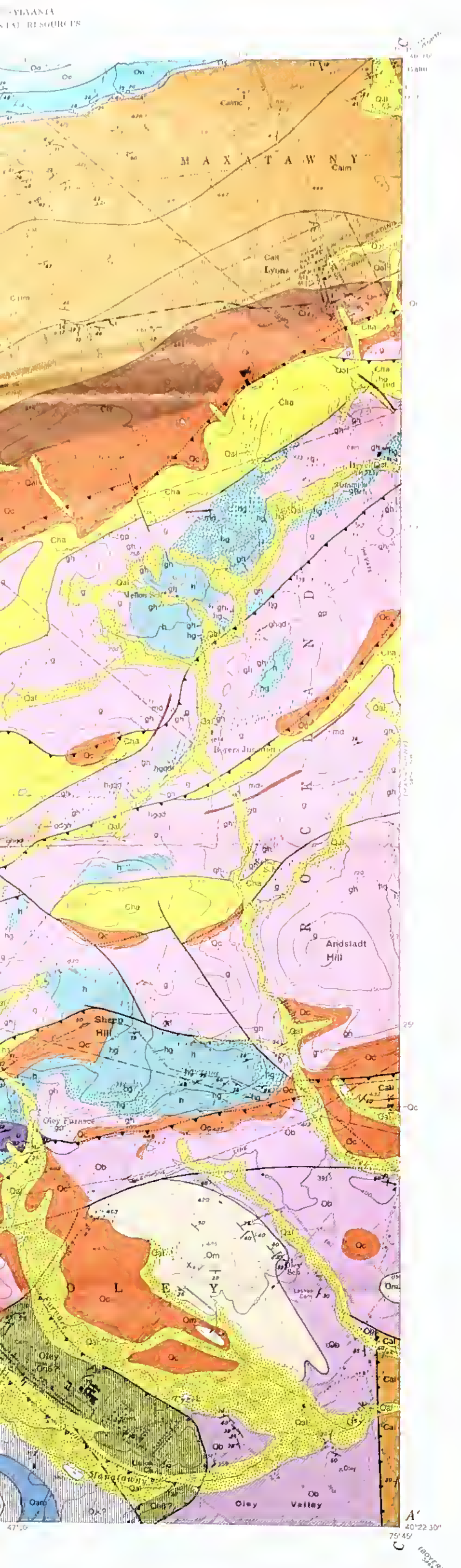
SCALE 1:24[illegible]

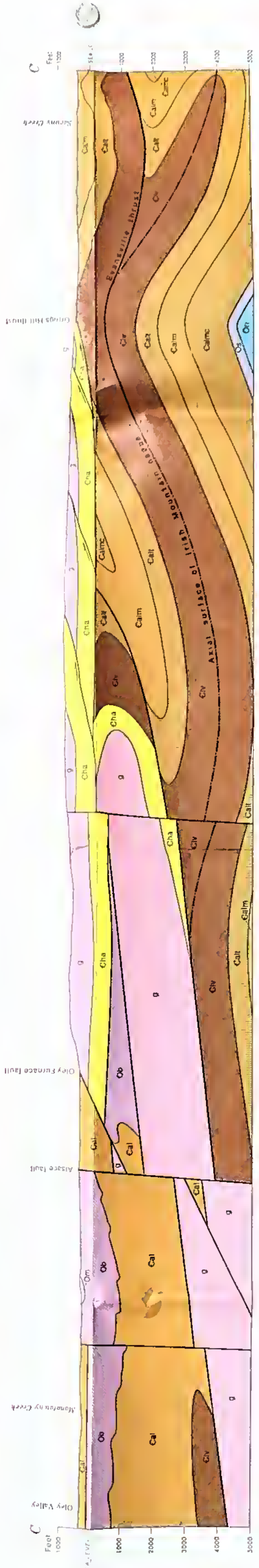
CROSS SECTIONS

(Horizontal scale same as map scale, no vertical exaggeration)









Geology of Cambrian and younger rocks based on field mapping by D. B. MacLachlan from 1961-78. Geology of Precambrian rocks and the Hardyston Formation from Buckwalter (1962), with minor modifications by MacLachlan.

Albert E. VanOlden, Cartographer

NIA

QUATERNARY

▇

MAN-MADE DEPOSITS

Slag piles and impoundments of dredged alluvium. Only major deposits are shown.

Qal

ALLUVIUM

Saturated or periodically wet deposits along streams. Predominantly fine grained, and silty to sandy, has scattered coarser clasts along the Schuylkill River. Deposits along minor streams are variable depending on stream gradient and lithologies traversed. Alluvial anthracite is abundant in some of the Schuylkill River deposits. Thickness is variable, ranges from 0 to fairly thick, maximum thickness is unknown.

Qc

COLLUVIUM

Gravelly silt containing abundant pebbles, cobbles, and some boulders of quartzite and subordinate gneiss. Thickness is 0 to 30+ m (0 to 100+ ft).

Qt

TERRACE GRAVELS

Rounded pebbles and some cobbles of white to tan quartzite, and subordinate pink and maroon sandstone and siltstone clasts derived from Silurian and younger rocks. Generally thin but at least up to 6 m (20 ft) thick locally.

TRIASSIC

Td

DIABASE

Dark gray fine grained diabase dike. Fresh rock consists predominantly of plagioclase and greenish-black pyroxene showing little alteration. Considered to be Jurassic in age by some

HAMBURG SEQUENCE

(These allochthonous lithotectonic units are in probable order of emplacement and may be in reverse order of age.)

LOWER AND MIDDLE ORDOVICIAN

Oh7

LITHOTECTONIC UNIT 7

Olive-weathering gray shale and siltstone and maroon shale. Minor beds of fine-grained brown sandstone.

Oh6 — Oh6c

LITHOTECTONIC UNIT 6

Greenish-brown siltstone, claystone, and shale containing local beds of quartz-pebble graywacke conglomerate (Oh6c) and graywacke.

Oh5

LITHOTECTONIC UNIT 5

Purple, green, and tan shale or claystone, strongly cleaved.

Oh4 — Oh4a — Oh4l

LITHOTECTONIC UNIT 4

Predominantly thick-bedded to massive, greenish-gray silty shale and micaceous siltstone. Zones (Oh4l) of dark-gray ribbon limestone, limestone, conglomerate, and quartzose calcarenite increase toward west. A zone (Oh4a) containing some graywacke and phyllitic limestone may be a distinct slice

Oh3

LITHOTECTONIC UNIT 3

Interbedded maroon and olive, coarsely micaceous siltstone.

Oh2 — Oh2l

LITHOTECTONIC UNIT 2

Dark gray shale and siltstone, tending to be slightly olive or greenish-gray in the coarser grained rocks. Usually perceptibly sericitic, locally dolomitic or calcareous. Intercalated zones (Oh2l) of dark gray ribbon limestone and limestone conglomerate having a shale matrix.

Oh1

LITHOTECTONIC UNIT 1

Olive-weathering gray shale and siltstone and thick interbeds of brown or gray calcareous graywacke and graywacke.

MIDDLE ORDOVICIAN

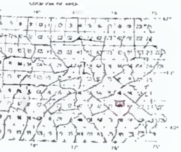
LOWER ORDOVICIAN

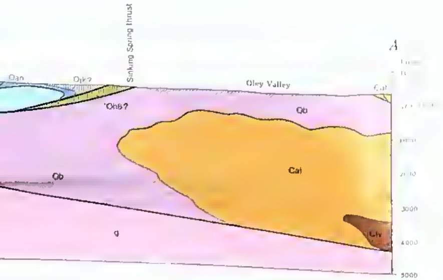
UPPER CAMBRIAN

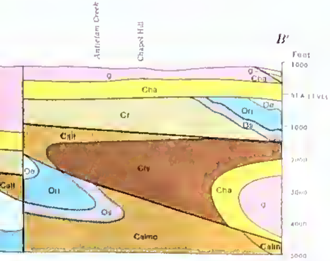
Geology of Cambrian and younger rocks based on field mapping by D. B. MacLachlan from 1961-78. Geology of Precambrian rocks and the Hardyston Formation from Buckwalter (1962), with minor modifications by MacLachlan

Albert E. VanOlden, Cartographer

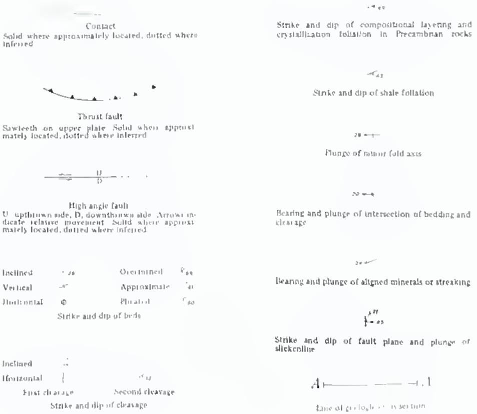
A







SYMBOLS



Contact
Solid where approximately located, dotted where inferred

Thrust fault
Sawteeth on upper plate. Solid where approximately located, dotted where inferred

High angle fault
U, upthrown side, D, downthrown side. Arrows indicate relative movement. Solid where approximately located, dotted where inferred

Inclined
Vertical
Horizontal
Overturned
Approximate
Pliated
Strike and dip of beds

Inclined
Horizontal
First cleavage
Second cleavage
Strike and dip of cleavage

Strike and dip of compositional layering and crystallization foliation in Precambrian rocks

Strike and dip of shale foliation

Plunge of minor fold axis

Bearing and plunge of intersection of bedding and cleavage

Bearing and plunge of aligned minerals or streaking

Strike and dip of fault plane and plunge of slickenline

Line of geologic cross section

PRECAMBRIAN

EXPLANATION

QUATERNARY

MAN MADE DEPOSITS

Slag piles and impoundments of dredged alluvium. Only major deposits are shown.

Qal

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Qc

COLLUVIUM

Gravelly silt containing abundant pebbles, cobbles, and some boulders of quartzite and subordinate gneiss. Thickness is 0 to 30+ m (0 to 100 ft).

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TRIASSIC

Trd

DIABASE

Dark-gray fine-grained diabase dike. Fresh rock consists predominantly of plagioclase and greenish-black pyroxene showing little alteration. Considered to be Jurassic in age by some.

HAMBURG SEQUENCE

[These allochthonous lithotectonic units are in probable order of emplacement and may be in reverse order of age.]

LOWER AND MIDDLE ORDOVICIAN

Oh7

LITHOTECTONIC UNIT 7

Olive-weathering gray shale and siltstone and maroon shale. Minor beds of fine-grained brown sandstone.

Oh6 Oh6c

LITHOTECTONIC UNIT 6

Greenish-brown siltstone, claystone, and shale containing local beds of quartz-pebble graywacke conglomerate (Oh6c) and graywacke.

Oh5

LITHOTECTONIC UNIT 5

Purple, green, and tan shale or claystone, strongly cleaved.

Oh4 Oh4a Oh4l

LITHOTECTONIC UNIT 4

Predominantly thick-bedded to massive, greenish-gray silty shale and micaceous siltstone. Zones (Oh4l) of dark-gray ribbon limestone, limestone conglomerate, and quartzose calcarenite increase toward west. A zone (Oh4a) containing some graywacke and phyllitic limestone may be a distinct slice.

Oh3

LITHOTECTONIC UNIT 3

Interbedded maroon and olive, coarsely micaceous siltstone.

Oh2 Oh2l

LITHOTECTONIC UNIT 2

Dark-gray shale and siltstone, tending to be slightly olive or greenish-gray in the coarser grained rocks. Usually perceptibly sericitic, locally dolomitic or calcareous. Intercalated zones (Oh2l) of dark-gray ribbon limestone and limestone conglomerate having a shale matrix.

Oh1

LITHOTECTONIC UNIT 1

Olive-weathering gray shale and siltstone and thick interbeds of brown or gray calcareous graywacke and graywacke.

LEBANON VALLEY SEQUENCE — LEHIGH VALLEY SEQUENCE

MIDDLE ORDOVICIAN

Om — Om

MARTINSBURG FORMATION

Dark-gray clay slate, bedding is sometimes discernible from thin, silty laminae. Slightly calcareous locally. Only the lower part is preserved. Maximum thickness in the area is probably less than 300 m (1000 ft).

Ojk — Ojk

JACKSONBURG FORMATION

Very dark gray argillaceous limestone, obscurely thick-bedded and strongly cleaved, weathers to buff shaly chips. Two thin metabentonite beds are locally exposed in the lower part. Thickness is probably less than 90 m (300 ft).

Oan

ANNVILLE FORMATION

Thick-bedded light-gray high-calcium limestone. Thickness ranges from 0 to 11 m (0 to 110 ft). There is an erosion surface above.

LOWER ORDOVICIAN

Oo — Oo

ONTELAUNEE FORMATION

Predominantly medium-dark gray, finely crystalline dolomite in 30- to 60-cm (1- to 2-ft) beds. Massive to faintly laminated; weathers grayish yellow. Variably dolomitized beds of medium gray limestone occur, especially in the lower part of the section. Dark gray chert in beds up to 1 m (3 ft) is present at the base. Thickness is 200 m (650 ft).

Oe — Oe

EPLER FORMATION

Thick interbeds of medium- to medium dark-gray, finely crystalline limestone, weathering light gray; has conspicuous yellow dolomitic mottles or laminae, and subordinate medium dark-gray, finely crystalline dolomite, which weathers grayish yellow. Sharpstone conglomerate, fossil fragment and oolitic beds or lenses occur in places. Thickness is 245 m (800 ft).

Or — Or

RICKENBACH FORMATION

Medium- to dark-gray, coarsely crystalline dolomite predominates in the lower part, medium- to medium-light-gray, finely crystalline dolomite in the upper part. Some partly dolomitized limestone beds, chert beds, nodules, and stringers. Thickness is 171 m (560 ft) in the west to about 215 m (700 ft) in the east.

Os — Os

STONEHENGE FORMATION

Medium-light-gray to medium-gray, finely crystalline, thick-bedded limestone, predominantly containing dark siliceous laminae and, less commonly, buff-weathering irregular dolomitic laminae and mottles. Sharpstone conglomerate beds and fossil-fragment lenses occur in places. Dolomite beds are rare in the west, but increase eastward. Thickness is 76 m (250 ft) in the west to 30 m (100 ft) in the east.

Ob — BEEKMANTOWN GROUP

UPPER CAMBRIAN

CONOCOCHEAGUE GROUP

Cr

RICHLAND FORMATION

Medium-gray thick dolomite and limestone interbeds. Limestone beds commonly have argillaceous or silty laminae and may be sandy; beds contain scattered nodules and stringers of brownish-gray chert, some oolitic and cryptozoon layers and discrete dolomitic sandstone beds. Thickness is 510 m (1700 ft); partly exposed.

Cm

MILLBACH FORMATION

Light-gray thick-bedded limestone and subordinate dolomite, appears in cross section only. Estimated thickness of 100 m (300 ft) is present above the thrust.

UPPER CAMBRIAN

Calmc

MAIDEN CREEK MEMBER

Medium- to medium-dark-gray, thick-bedded dolomite and magnesian limestone, medium-light-gray in places. Brownish-gray-weathering dark-gray chert stringers and nodules are common and characteristically very abundant as float fragments. Detrital carbonates containing abundant brownish-gray-weathering silty laminae predominate, penecontemporaneous conglomerate and oolitic, massive to obscurely laminated dolomites are present; cryptozoon beds are very rare. Thickness is 375 m (1230 ft).

Calm

MUHLENBERG MEMBER

Medium- to medium-light-gray, thick-bedded magnesian limestone and dolomite, dark-gray in places. Contains scattered calcareous sandstone beds up to 1-1/2 m (5 ft). Detrital carbonates having abundant silty to sandy laminae predominate, pelletoidal calcarenites are common, oolitic and cryptozoon beds are present. Surface is characterized by sandy float fragments. Up to 7 m (23 ft) of grayish-yellow-green shale may be present at the top. Thickness is 240 m (800 ft).

Calt

TUCKERTON MEMBER

Predominantly medium gray and light- to medium-dark-gray, magnesian to calcareous limestone and dolomite in 20-cm to 1-m (8-in. to 40-ft) beds. Detrital carbonates containing abundant silty to shaly laminae predominate, but algal and oolitic beds are common. Contains sparse but widely distributed, black cryptozoon chert. Has orange-brown-weathered calcareous siltstone about 3 m (10 ft) thick at the top in the Temple quadrangle. Thickness is 150 to 200 m (500 to 650 ft).

Cal — ALLENTOWN FORMATION

MIDDLE CAMBRIAN

Clv

LEITHSVILLE FORMATION

Predominantly medium- to dark gray, or light-olive-gray, crystalline dolomite, weathering to light gray, grayish orange, or yellowish brown. Beds up to 3 m (10 ft) thick of planar laminar predominate, but cross-laminated, massive, oolitic, and penecontemporaneous conglomerate beds are common. Pink to gray, mottled chert and dark-gray chert are present in float. Thin shale and dolomitic shale interbeds and scattered sand grains are common throughout. Upper part is very shaly and possibly calcareous. Estimated thickness is 300 m (1000 feet).

LOWER CAMBRIAN

Cha

HARDYSTON FORMATION

Typically light gray, ranging from nearly white to dark gray, light-buff, and reddish-gray, fine- to medium-grained quartzite and feldspathic sandstone in 15- to 50-cm (6- to 20-in.) beds. Usually massive but may have thin laminations or cross-bedding. Skolithus present in upper part. A quartz-pebble conglomerate, 8 m (25 ft) thick, containing coarse feldspathic sandstone in a minor dark-gray argillaceous matrix, occurs at the base and is shown by a circle pattern; it is transitional through about 15 to 30 m (50 to 100 ft) of conglomeratic, feldspathic quartzite to the typical rock.

p

PEGMATITE

(used as combining form only)

White to light-brown pegmatite, grain size is variable, ranges up to about 60 mm. Mineral proportions are highly variable and include quartz, microcline, and perthite in all occurrences; sodic plagioclase is less abundant; orthoclase, biotite, and muscovite are uncommon. Forms small dikes and seams in paragneisses and migmatites which cannot be separately mapped but are noted as a migmatite component where especially abundant.

qd

QUARTZ DIORITE GNEISS

Dark-greenish-gray to dark-gray, weakly to moderately foliated gneiss, 0.5 to 3 mm in size. Andesine (An31-37), 58% to 74%; quartz, 15 to 35%; hornblende, about 15%; minor augite, hypersthene, biotite, garnet, and magnetite; locally up to 10% potassium feldspar. Gradational into granitic and hornblende gneisses; appears to have originated by nearly complete melting during migmatization.

MIDDLE ORDOVICIAN(?)

md

METADIABASE

Dark greenish-gray diabase, weathers medium gray to brown, forming rounded cobbles and boulders. Grain size ranges from 0.5 to 1 mm. In fresh rock, labradorite or andesine (An41-60) make up 40 to 60% of total composition; augite, 25 to 40%; magnetite, 5 to 10%; also contains accessory quartz, apatite, and pyrite. Feldspar is usually much sericitized, augite is partly replaced by hornblende and biotite and shows some alteration to chlorite and epidote.

MIGMATITES AND CLOSELY INTERBANDED GNEISSES

Predominant color indicates most abundant gneiss. Patterns indicate approximate abundance of minor gneissic constituents in the migmatites as shown below. The first letter indicates the most abundant gneiss, the second or third letters the successively minor gneisses of the migmatites.

grh

Graphitic gneiss interbedded with approximately 20 to 30 percent hornblende gneiss.

ggr

Granitic gneiss having approximately 20 to 30 percent assimilated or partly assimilated and injected graphitic gneiss.

gh

Granitic gneiss having approximately 10 to 20 percent assimilated or partly assimilated and injected hornblende gneiss.

gh

Granitic gneiss having approximately 20 to 30 percent assimilated or partly assimilated and injected hornblende gneiss.

gh

Granitic gneiss having approximately 30 to 40 percent assimilated or partly assimilated and injected hornblende gneiss.

gph

Granitic gneiss having approximately 20 to 30 percent associated pegmatite and 20 to 30 percent assimilated or partly assimilated and injected hornblende gneiss.

ghqd

Granitic gneiss having approximately 20 to 30 percent assimilated or partly assimilated and injected hornblende gneiss and quartz diorite gneiss.

ghqd

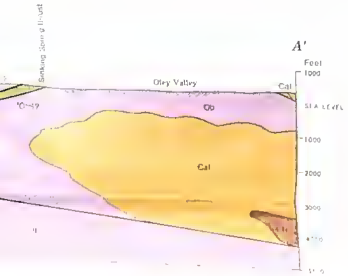
Granitic gneiss having approximately 30 to 40 percent assimilated or partly assimilated and injected hornblende gneiss and quartz diorite gneiss.

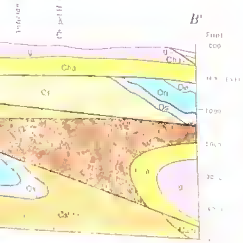
gp

Granitic gneiss associated with approximately 30 to 40 percent pegmatite.

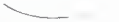
gqd

Granitic gneiss injected or assimilated by approximately 20 to 30 percent quartz diorite gneiss.



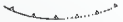


SYMBOLS



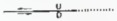
Contact

Solid where approximately located, dotted where inferred.



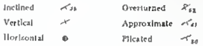
Thrust fault

Sawteeth on upper plate. Solid where approximately located, dotted where inferred.

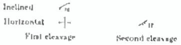


High-angle fault

U, upthrown side, D, downthrown side. Arrows indicate relative movement. Solid where approximately located, dotted where inferred.



Strike and dip of beds



Strike and dip of cleavage

Strike and dip of compositional layering and crystallization foliation in Precambrian rocks

Strike and dip of shale foliation

Plunge of minor fold axis

Bearing and plunge of intersection of bedding and cleavage

Bearing and plunge of aligned minerals or streaking

Strike and dip of fault plane and plunge of slickenline

Line of geologic cross section

PRECAMBRIAN

White to light-brown pegmatite; grain size is variable, ranges up to about 60 mm. Mineral proportions are highly variable and include quartz, microcline, and perthite in all occurrences; sodic plagioclase is less abundant; orthoclase, biotite, and muscovite are uncommon. Forms small dikes and seams in paragneisses and migmatites which cannot be separately mapped but are noted as a migmatite component where especially abundant.

qd

QUARTZ DIORITE GNEISS

Dark-greenish-gray to dark-gray, weakly to moderately foliated gneiss, 0.5 to 3 mm in size. Andesine (An31-37), 58% to 74%; quartz, 15 to 35%; hornblende, about 15%; minor augite, hypersthene, biotite, garnet, and magnetite; locally up to 10% potassium feldspar. Gradational into granitic and hornblende gneisses; appears to have originated by nearly complete melting during migmatization.

g

GRANITIC GNEISS

Light-gray gneiss, tan or pink in places; weathers to large slabs and spheroidal boulders. Grain size is typically 1 mm, but is up to 10 mm in pegmatitic phases. Foliation is poorly defined in massive rocks but prominent in migmatites. Microcline and perthite typically make up 20 to 30% of the whole (range, 1 to 90%); quartz, typically 20 to 30% (range, 8 to 43%); oligoclase and sodic andesine, 5 to 25% in half of occurrences; hornblende, 0 to 14%; biotite, 0 to 1%; magnetite, 0 to 3%; accessory zircon, apatite, and ilmenite. Ferromagnesian minerals are sparse in typical rocks, but become more abundant in migmatites.

h

HORNBLENDE GNEISS

Dark gray to black, well-foliated gneiss; weathers to resistant brownish blocks. Grain size is 1 to 2 mm. Hornblende typically makes up 50% of unit, but varies from 10 to 70%. Labradorite (An60-63) is the other major constituent. Clinopyroxene and orthopyroxene are present separately or together in amounts from 0 to 10%. Biotite is rare but locally forms up to 15% of unit. Garnet is locally present up to 5%. Quartz is rare or lacking except in migmatic zones.

QUARTZ-BIOTITE-FELDSPAR GNEISS

Light-gray- to nearly white weathering, sugary-textured gneiss which has foliation defined only by biotite layers. Splits readily into thin slabs and becomes somewhat friable. Composed of quartz, 30%; orthoclase, 30%; andesine (An36), 30%; biotite, 5%; and minor magnetite, zircon, sericite, and clay. Minor unit; is exposed in only four outcrops.

gl

GRAPHITIC GNEISS

Light-gray gneiss, pinkish in places; weathers easily to soft, brown and white speckled, small slabs. Grain size is typically 0.5 mm, ranging to 6 mm in metasomatic zones. Predominantly quartz and potassium feldspar. Biotite is common, and forms up to 10% of total composition. Graphite is usually sparse but forms conspicuous 1- to 2-mm plates. Small amounts of hypersthene, garnet, and magnetite occur locally. Relict graphite may indicate presence in metasomatic granitic gneiss.

ghqd

Granitic gneiss having approximately 30 to 40 percent assimilated or partly assimilated and injected hornblende gneiss and quartz diorite gneiss.

gp

Granitic gneiss associated with approximately 30 to 40 percent pegmatite.

gqd

Granitic gneiss injected or assimilated by approximately 20 to 30 percent quartz diorite gneiss.

gqd

Granitic gneiss injected or assimilated by approximately 30 to 40 percent quartz diorite gneiss.

hg

Hornblende gneiss injected, assimilated, or replaced by approximately 10 to 20 percent granitic gneiss.

hg

Hornblende gneiss injected, assimilated, or replaced by approximately 20 to 30 percent granitic gneiss.

hg

Hornblende gneiss injected, assimilated, or replaced by approximately 30 to 40 percent granitic gneiss.

hgqd

Hornblende gneiss injected or assimilated by approximately 20 to 30 percent each of quartz diorite gneiss and granitic gneiss.

qdg

Quartz diorite gneiss having approximately 10 to 20 percent associated granitic gneiss.

qdg

Quartz diorite gneiss having approximately 20 to 30 percent associated granitic gneiss.

qdg

Quartz diorite gneiss having approximately 30 to 40 percent associated granitic gneiss.

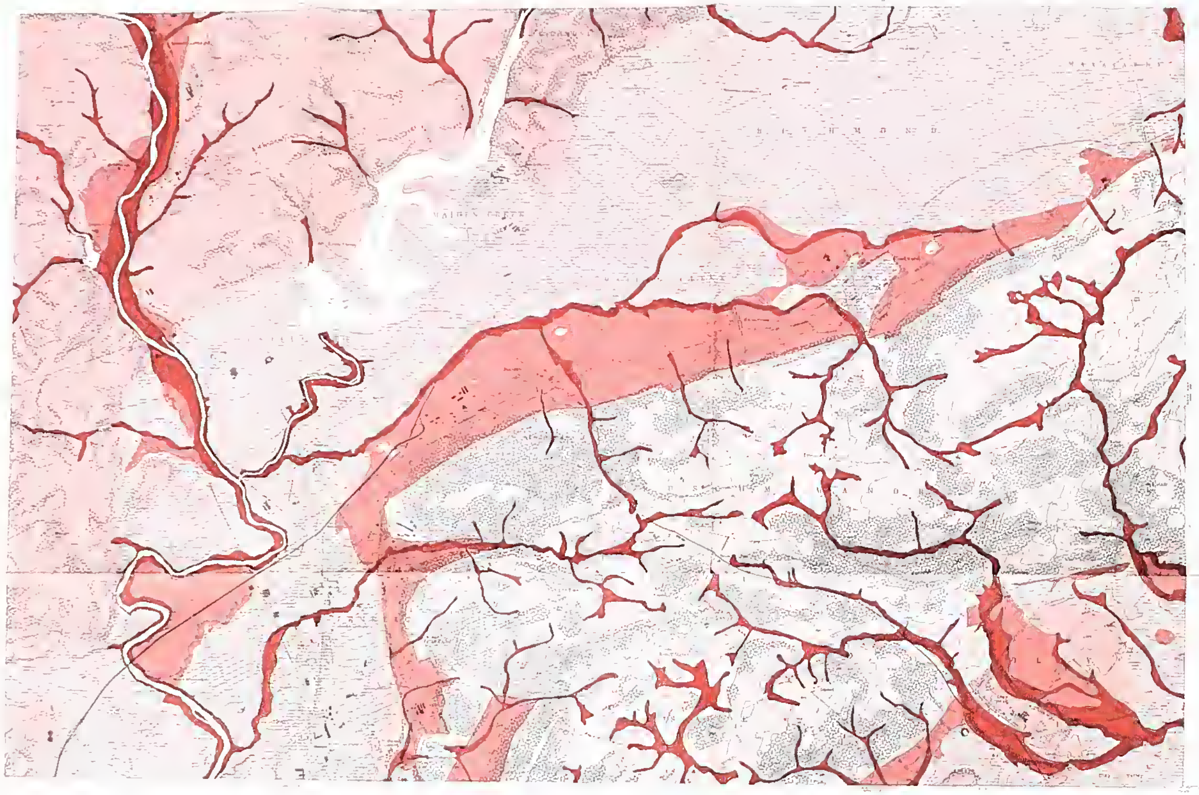
qdgh

Quartz diorite gneiss having associated granitic and hornblende gneiss.

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

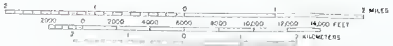
A 187ab, Plate 2



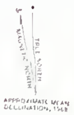
Albert E. VanOlden, Cartographer

MAP SHOWING MAJOR ENVIRONMENTAL GEOLOGY FACTORS IN THE TEMPLE AND FLEETWOOD QUADRANGLES, BERKS COUNTY, PENNSYLVANIA

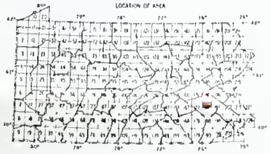
SCALE 1: 48,000



CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL



APPROXIMATE MEAN DECLINATION, 1968



EXPLANATION

☐

AREAS STRONGLY AFFECTED BY THE ACTIVITIES OF MAN

▨

FLOOD-PRONE AREAS DEFINED BY THE U.S. GEOLOGICAL SURVEY

Average recurrence of flooding is 50 to 100 years at the margins and more frequent in the lower lying parts. Generally unsuitable for most kinds of development because of flood risk. Encroachments may obstruct high-water flow and increase the area of flood risk.

🟥

FLOODPLAINS: NEARLY LEVEL AREAS OF ALLUVIAL DEPOSITS ADJACENT TO MODERN STREAMS

Alluvial material is easily excavated, though cribbing may be required, especially if wet. Alluvial deposits generally provide poor foundations, but they are commonly thin in this area, and adequate foundations for major structures can usually be made by excavation to underlying bedrock.

The deposits are saturated and have good permeability, but are mostly thin and not well developed for water supply. Where the risk of flooding is acceptably low, high water tables and poor drainage are the major limitations on land use. Conventional on-site sewage disposal systems are usually not feasible.

🟥

AREAS OF GRAVEL-BEARING TERRACE AND COLLUVIAL DEPOSITS

Unconsolidated gravel-bearing deposits underlie well-drained, gentle to moderate slopes. They are easily excavated and provide adequate foundations except for heavy structures. The material is generally suitable for on-site sewage disposal and sanitary landfills.

The deposits are variable in thickness, reaching a maximum of greater than 100 feet (30 m) but usually much thinner and sometimes enclosing small areas of bedrock outcrop. The gravel deposits sometimes overlie unusually large thicknesses of unconsolidated residuum which has been protected from erosion by the capping deposit. In such areas, the great depth to bedrock may make sound foundations for heavy structures difficult to establish.

The deposits are well drained, unsaturated to moderate depths, and provide some potential for good water supplies from properly screened wells at the base of slopes.

The deposits delineated have properties and composition substantially different than the normal residuum that they overlie. The colluvial deposits grade upslope into residual weathered material overlying quartzite and gneiss. In this area the distinction between transported and strictly residual mantle is often difficult and is of no practical consequence; colluvial material above gneiss and quartzite is not distinguished here. Where these deposits overlie carbonate rocks, the soluble character of the substrate may sometimes affect foundations for heavy structures, but a variety of factors evidently related to the composition of the soil, the topographic position of the deposit, and the depth of the water table make sinkholes and surface-collapse features very uncommon in these areas.

▨

AREAS HAVING SLOPES PREDOMINANTLY GREATER THAN 15 PERCENT (8.53 DEGREES)

The statutory upper limit of slopes for conventional on-site sewage-disposal systems and sanitary landfills is 15 percent. This slope also approximates the value at which slope becomes a major factor in many aspects of land use. Increased difficulties in engineering design, site preparation, highway grades, erosion control, and related problems place moderate to severe limitations on this more steeply sloping land.

☐

HILLS UNDERLAIN BY PREDOMINANTLY SHALY ROCKS

Shales associated with some coarser grained siliciclastic rocks and a small amount of limestone support a rolling upland less than 200 feet (60 m) above adjacent carbonate rocks. The upland is surmounted by a few hills supported by more resistant sandstones and conglomerates and incised by fairly steep sided valleys.

Soils are often thin but grade down into a zone of weathered bedrock often 20 to 50 feet (6 to 15 m) thick. The weathered rock is soil-like in some respects and may be suitable for

HILLS UNDERLAIN BY PREDOMINANTLY SHALY ROCKS
(continued)

on-site sewage disposal and sanitary landfills. It is easily excavated, provides generally good foundations, and stands well in temporary exposures. Permanent excavations should be finished to a moderate slope.

Fresh shale can usually be excavated by heavy equipment without blasting. Ledges of sandstone or limestone may be more difficult. Much of the rock stands moderately well in steep permanent cuts, but conservative practice suggests the same treatment as for weathered shale.

Areas of limestone enclosed in the shales may be particularly subject to sinkhole development and solution collapse. The major areas of limestone within the shales are shown on Plate 1, but unmapped lenses and zones may be present. They represent the major geologic hazard in this area.

Water supply for domestic or moderate commercial use is generally available, but supply limitations may be the principal impediment to industry or large-scale development. The best yields are obtained from the limestone zones.

Natural slopes are stable with respect to rapid mass movements, but may show evidence of surficial creep. Creep zones as much as 7 feet (2 m) thick have been observed on some slopes though creep may have been active through this thickness only during Pleistocene climatic extremes.

▨

LOWLANDS OF CARBONATE BEDROCK HAVING RESIDUAL SOIL

Carbonate rocks underlie gently rolling valleys having steeper slopes locally, adjacent to incised through-flowing streams. A nearly fully integrated system of connected drainageways crosses the carbonate-rock area, but most are not occupied by permanent streams. There is little surface runoff except during extreme rainfall events, but subsurface drainage is excellent. The water table commonly lies below the bedrock surface, and soil wetness is a problem only in some scattered undrained depressions.

The bedrock surface is very irregular due to solution, and residual soil thickness varies considerably in small areas. Soil is easily excavated, though rock ledges requiring blasting may be encountered at shallow depths almost anywhere. Soils are generally suitable for on-site sewage disposal and sanitary landfills, but effluent or leachate reaching bedrock may be widely and rapidly spread. Where such facilities are located on soil too shallow to effectively process the influx, or where breached by sinkhole development, they may produce widespread groundwater pollution.

The small portion of this area occupied by the Jacksonburg Formation (see Plate 1) provides weak foundations and is a poor aquifer. Otherwise, sound bedrock provides excellent foundations for all structures; it is excavated with difficulty, requires blasting, and maintains steep cut slopes. Risks attendant on sinkhole development and solution cavities in foundation rocks should be carefully investigated at any construction site.

Most carbonate rocks provide abundant groundwater though well yields may be quite variable owing to variations in the openness of water-bearing fractures. These supplies are particularly subject to pollution, and groundwater underlying some of the older communities is considered unfit for public water supply.

The carbonate rock lowlands are premium farm land. They are generally suitable for almost all other kinds of development but present the risk of sinkholes and solution cavities which may increase both initial and maintenance costs for non-agricultural uses. Disturbance of the hydrologic equilibrium by heavy pumping, by obstruction of recharge due to paving or construction, and by concentration of runoff may cause sinkhole development in areas where this had not previously been a problem.

☐

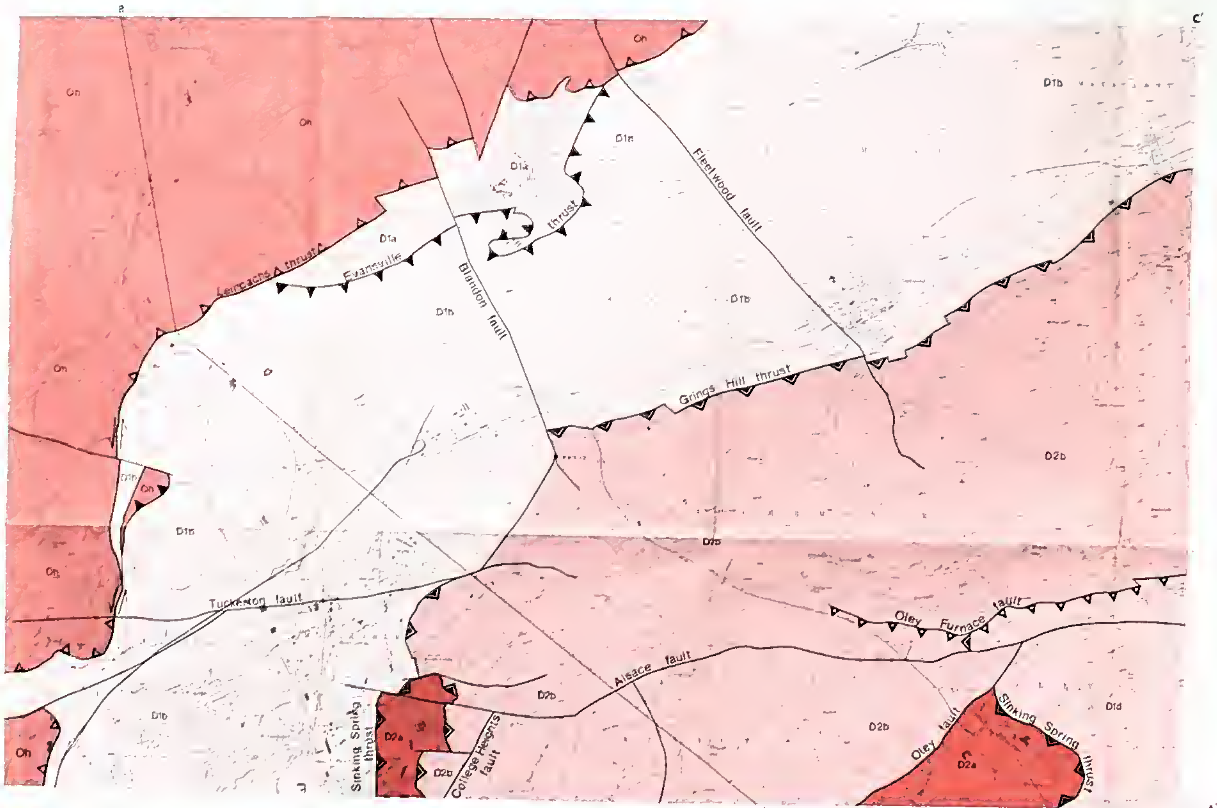
HILLS UNDERLAIN BY GNEISS AND QUARTZITE

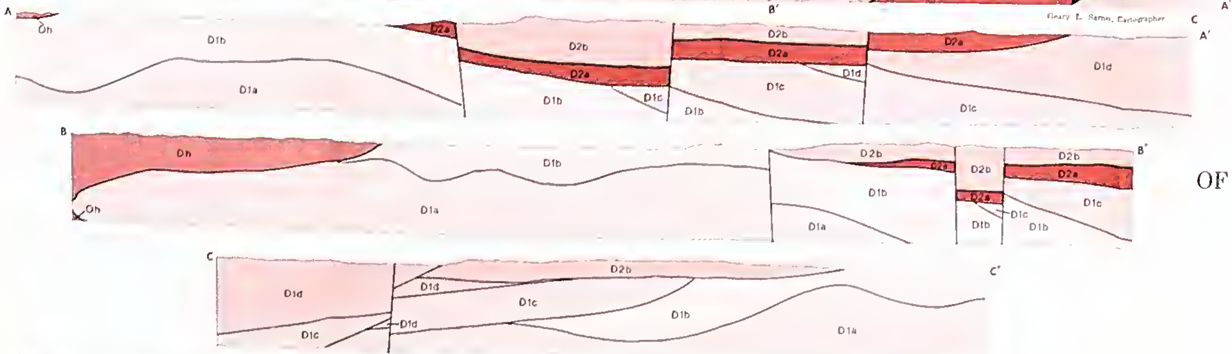
Gneiss and quartzite support hills sometimes rising to more than 600 feet (180 m) above adjacent lowlands. Moderately steep to steep slopes are common. They are naturally stable except for some surficial creep, but quite subject to erosional damage when disturbed.

Rock exposures are rare, and thick stony soils are common except on steep slopes. Surficial material is easily excavated, though large boulders may be encountered, and provides good foundations for residential structures. It is suitable for on-site sewage disposal and sanitary landfills where slope conditions permit. There is good surface drainage, and the less sloping portions are generally suitable for development.

Bedrock is sparsely fractured, very difficult to excavate, requires blasting, provides excellent foundations for heavy structures, and maintains a steep cut slope. The rocks are poor aquifers but usually yield adequate groundwater for domestic use.

Small underground workings from old iron mines are sometimes present. They are developed in sound rock and present little risk of surface collapse, though they may be an unexpected complication in major excavations as their locations are often unknown.





Geary L. Sarno, Cartographer

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EXPLANATION

Major structural levels are shown in order of superposition

D2b

LEVEL OF GRINGS HILL THRUST PLATE

The upper main plate emplaced in the Alleghanian deformation (D2). Rocks are essentially identical to the older part of the Irish Mountain nappe.

D2a

LEVEL OF SINKING SPRING THRUST PLATE

The lower main thrust plate emplaced in the Alleghanian deformation (D2). It was apparently derived from the Lebanon Valley nappe.

D1d

LEVEL OF SURFACE ROCKS
IN THE NORTHERN OLEY VALLEY

Apparently related in lithology and genesis to the Irish Mountain nappe. Emplacement is clearly before D2a and is probably an effect of the Taconic deformation (D1).

D1c

BURIED LEVEL OF CRYSTALLINE ROCKS
IN THE OLEY VALLEY VICINITY

Implied by projection of surface structure and aeromagnetic data. This level is deduced to be closely related to level D1d and generally related to the Irish Mountain nappe.

D1b

UPPER SUBLEVEL OF THE IRISH MOUNTAIN NAPPE

Emplaced in the Taconic deformation (D1).

D1a

LOWER SUBLEVEL OF THE IRISH MOUNTAIN NAPPE

Emplaced in the Taconic deformation (D1).

On

HAMBURG SEQUENCE ALLOCHTHONOUS ROCKS

Seven lithotectonic units emplaced during the Taconic deformation, but at least in part before nappe development in the shelf rocks.

SYMBOLS

Thrust faults developed in the Taconic deformation (D1)

Thrust faults that may have been active in both Taconic (D1) and the Alleghanian (D2) deformations

Thrust faults developed in the main stage of the Alleghanian deformation (D2)

Probable late Alleghanian (D3) steep thrusts developed after main-stage Alleghanian deformation

High-angle faults, probably of Mesozoic age, except for tear segment of the Leinbachs thrust

TECTONIC MAP
OF THE TEMPLE AND FLEETWOOD QUADRANGLES,
BERKS COUNTY, PENNSYLVANIA